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No. 202

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF AN OSCILLATING  
AIRSTREAM (KATZMAYR EFFECT) ON THE CHARACTERISTICS OF AIRFOILS.

By Toussaint, Kerneis and Girault.

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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF AN OSCILLATING  
AIRSTREAM (KATZMAYR EFFECT) ON THE CHARACTERISTICS OF AIRFOILS.

By Toussaint, Kerneis and Girault.

At the request of the Service Technique de l'Aeronautique, we carried out, during the summer of 1923, a series of experiments relating to the action of an airstream oscillating vertically on supporting surfaces. Experiments of this kind had previously been made by Mr. Katzmayer, Director of the Vienna Aerodynamic Laboratory. The object of our experiments was to verify Mr. Katzmayer's very interesting results and, if possible, to obtain more complete data on the effect of the amplitude and velocity of the oscillations of the airstream.

First, I will briefly recall the results obtained by Mr. Katzmayer. (See "Zeitschrift für Flugtechnik und Motorluftschiffahrt" of March 31 and April 15, 1922; also Bulletin No. 7 of the S.T.Ae.)

In the first tests, the wing was placed in an airstream of fixed direction and the angle of attack was made to vary periodically by oscillation. Fig. 1 shows the results obtained. We see that when the wing oscillates in an airstream having a fixed direction, the polar curve becomes more and more unfavorable as the

oscillation increases in amplitude. The points corresponding to a mean angle of attack seem to fall on one line which converges to a single point or "pole." This point would correspond to a very large amplitude of oscillation for which the wing would behave like a body subject to only one drag and lift.

No new data were acquired from studying the effect of the number of oscillations (20 to 50 per minute) and the velocity of the airstream. In these experiments the model oscillated about an axis parallel to the span.

When the wing was made to oscillate parallel to itself and perpendicular to the airstream, it was found that the polar curves were not quite so good as when the model was at rest.

In a second set of experiments the airstream was made to oscillate perpendicular to the span of the wing, fixed in the usual way to the aerodynamic balance. The airstream was made to change its direction by means of deflecting blades mechanically actuated. The results obtained showed considerable improvement in the polar curves. The principal advantage is the decrease of drag for a given lift - a decrease which becomes more and more marked as the oscillations increase in amplitude. We even noticed negative drags for quite good values of lift.

Various rates of oscillation were tried - from 27 to 106 per minute - without any appreciable difference in the results.

The last set of experiments dealt with simultaneous oscillation of wing and airstream. The oscillations of the latter were

such as to tend to increase the angle of attack of the wing to a maximum. It appeared that this superposing of effects previously obtained separately was not favorable for obtaining better aerodynamical conditions.

Object.— These experiments were intended to reproduce some of Katzmayer's experiments at the Vienna Aerodynamical Laboratory, the results of which were given in the "Zeitschrift für Flugtechnik und Motorluftschiffahrt," Nos. 6 and 7, of March 31, and April 13, 1922.

We also proposed to complete Katzmayer's work concerning the effect of the rapidity of oscillation.

Experimental Methods.— All these experiments were made in No. 1 wind tunnel, 2 m (6.56 ft.) diameter.

The parallelogram balance was also used, the models being either suspended by wires or supported from the walls.

The device for producing variations in the direction of flow is shown in Fig. 2. It consists of a unit of 13 symmetric biconvex blades oscillating about horizontal axes passing through the entering edge of the blades. Oscillation is controlled by a set of articulated levers with connecting rod and crank. The crankshaft is driven at constant speed by transmission gear actuated by a small electric motor with a continuous current of 120 volts.

The speed of the motor may be regulated by inserting resistances in the primary and secondary circuits. Furthermore, the

transmission gear has a three speed belt drive permitting three different speeds of oscillation for one engine speed. Thus a low speed of oscillation corresponds to 320 revolutions of the crankshaft and 100 oscillations in 90 seconds, (1.11 per second); mean speed gives 315 revolutions and 5.23 oscillations per second. High speed gives 302 revolutions and 10.06 oscillations per second.

For this rate of oscillation it was necessary to strengthen the attachments and supports of the transmission gear.

Amplitude of Oscillation.— The upper cranks had been made with a groove for sliding in the pin.

Later, we found it better to do away with the groove and have a number of holes each corresponding to a definite radius of the crank. The relation between the radius and the amplitude of oscillation is as follows:

Radius of crankshaft:	35 mm (1.38 in.)	Amplitude:	$\pm 10.25^{\circ}$
" " "	56.5 mm (2.22 in.)	"	$\pm 16.75^{\circ}$
" " "	80 mm (3.15 in.)	"	$\pm 23.1^{\circ}$

Preliminary Measurements. Calibration of Speeds of Airflow.

The oscillating blades placed in the tunnel affected the measurements of the mean speed in function of static pressure,  $H_s$ , measured at the usual orifice (orifice No. 3).

(a) Horizontal Blades at Rest.

With the blades in a horizontal position, we studied the distribution of speed along a horizontal diameter corresponding to

the zone occupied by the leading edges of the wings tested.

The results of this investigation are given in Table I and shown in Fig. 3. We see that the ratio  $\frac{P_e}{H_s}$  between the figures given by the standard Pitot tube and those at the orifice of static pressure varies very little along the whole of the horizontal diameter investigated. We observe only two singular points (marked od and 2g) for which the ratio is much more variable. These points are those at which the standard Pitot tube is placed to the rear of the suspension wires (center bolt and left attachment of forward wires). The disturbance due to these obstacles is quite local and when the standard Pitot tube is moved a few millimeters to either side of the singular point the ratio  $\frac{P_e}{H_s}$  reassumes its normal value.

The mean value of  $\frac{P_e}{H_s}$  applicable for experiments with blades at rest is thus:

$$\frac{P_e}{H_s} = 1.06$$

The corresponding mean velocity will therefore be:

$$V_m = \sqrt{16 \times 0.85 \times 1.06 H_s} = \sqrt{14.42 H_s}$$

for a density 0.85 of the liquid used in the manometer.

A rapid investigation of the distribution of speed along a vertical diameter was also very satisfactory.

NOTE.- When there are no blades the ratio  $\frac{P_e}{H_s}$  has a mean value of 0.99 for the open tunnel. It would appear that the mean speed behind the fixed blades is increased by 3.5% by the presence

of the blades. This increase must disappear rapidly with distance from the rear of the blades. In the plan of the maximum cross-section of the blades it would doubtless be equal to the ratio of the corresponding sections of passage.

(The blades having a mean maximum thickness of 20 mm (.787 in.) and a total length of about 20 m (65.62 ft.), the area of passage vertical to the blades would be  $3.1 \text{ sq.m} - 0.4 = 2.7 \text{ sq.m}$  (29.06 sq.ft.). The corresponding increase of speed would therefore be, theoretically,  $\frac{3.1}{2.7} = 1.15$ .)

(b) Measurement of speed of airflow when the blades are moving  
(Amplitude  $\pm 10.25^\circ$ ).

Placing the standard Pitot tube at the mark (1 d) at 85 mm (3.35 in.) to the right of the center, we first verified that the ratio  $\frac{P_e}{H_s}$  was valid at this point for various speeds (see Table IIa).

We thus found that the mean value  $\frac{P_e}{H_s} = 1.056$  is constant within the speed limits useful for the tests.

Then, leaving the standard Pitot tube in the same place, we set the blades oscillating at the mean rate (6 oscillations per second). The results are shown in Table IIa. We see that the mean value of the ratio  $\frac{P_e}{H_s}$  becomes 1.092, indicating an increase of speed of 5.4% when the blades are moving.

But this result required confirmation because the standard Pitot tube remaining fixed in the oscillating air, its readings might depend on the obliquity of the airflow.

We therefore mounted another Pitot tube on a wind vane having a horizontal axis. We had thus an adjustable Pitot tube the mean direction of which would always be very nearly that of the oscillating airflow.

In the first test the adjustable Pitot tube was placed at 1 d with the blades horizontal and fixed (Table IIa'); under these conditions the mean value of  $\frac{P_e}{H_s}$  was found to be 0.97.

The blades were then set in oscillation (6 per second) (Table IIb'), when we found  $\frac{P_e}{H_s} = 0.995$ , that is, an increase in  $V^2$  of 2.5%.

The same test was then made with a pneumometer fixed at 1 d.

This instrument was thought to be the most suitable, for it is peculiarly insensible to changes of direction of the wind normal to its plane (unless, of course, the variations reach  $\pm 10^\circ$ ).

With the pneumometer fixed at 1 d and the blades horizontal and fixed we obtained (Table IIIa)  $\frac{P_n}{H_s} = 1.486$ .

With the blades oscillating at the rate of 6 per second we obtained (Table IIIb)  $\frac{P_n}{H_s} = 1.522$ .

The increase in  $V^2$  is thus  $\frac{1.522}{1.486} = 1.025$ , the same figure that we had found with the adjustable Pitot tube.

Under these conditions the mean speed of the airstream when the blades are oscillating at a mean rate of 6 per second will be given in function of  $H_s$  by the ratio:

$$V_m^2 = 14.42 \times 1.025 H_s = 14.8 H_s.$$

With the same pneumometer and by the same method we determined the



mean speed in the case of slow oscillation (1.17 per second).

We then found  $\frac{P_n}{H_S} = 1.057$ , that is an increase of 1.057. The speed in function of  $H_S$  will be given by

$$V_m^2 = 14.42 \times 1.057 H_S = 15.24 H_S.$$

Lastly, in the case of 11 oscillations per second, we found  $\frac{P_n}{H_S} = 1.51$ , or an increase in  $V^2$  of 1.016, whence

$$V_m^2 = 14.42 \times 1.016 = 14.67 H_S.$$

Other speed measurements were made by M. Brasier by means of various windmill anemometers. A special report on these will be drawn up by M. Brasier.

#### Study of the Variation of Direction.

(a) Use of Wind Vanes.— In the oscillating airstream we tried several types of wind vanes with horizontal axes.

A dihedral wind vane (similar to that used by Messrs. Toussaint and Lepere on airplanes) was mounted above a vertical mast and connected with a device for recording the movement.

It was found to yield fairly easily to the force of the airstream but when the speed of the wind changed, the amplitude and perhaps the rate of oscillation varied considerably.

A wind vane of the Constantin type brought to the laboratory by Mr. Idrac, had more marked defects. Its inertia was such that it did not move when the oscillations were at the rate of 6 per second, though the amplitude of the oscillations of the air must have been of the order of  $\pm 10^\circ$ .

The conclusion is that mechanical wind vanes are too inert to be affected by rapid variations of direction.

(b) Use of silk threads.— Silk threads from 10 cm (3.94 in.) to 12 cm (4.72 in.) long seemed much better for the purpose and we utilized them for determining the amplitude of oscillation of the airstream. Photographs were taken on which could be noted with satisfactory accuracy the angle at the top of the sector swept by the thread under the action of the airstream.

With a crank radius of 35 mm (1.38 in.) we measured the following angles:

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Amplitude of oscillation of a silk thread in the airstream.			
Velocity V =	21 m (68.9 ft.)	25 m (82 ft.)	27 m (88.6 ft./sec.)
1 osc. per sec.	+ 9°	+ 9.25°	+ 9.25°
6 " " "	+10°	+ 9.75°	

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During the course of the experiments we were led to re-measure the amplitude of oscillation of the airstream in function of the speed of oscillation and the speed of the stream.

For these measurements we again utilized a silk thread but reduced its length to about 60 mm (2.36 in.) in order to counteract the inertia of the thread itself. Moreover, instead of using photography we tried direct observation of the thread by means of a sight with a graduated dial.

We thus made the following measurements:

1. Maximum deflections of the airstream when the blades are at rest.

The greatest deflection of the airstream when the blades are at rest and are brought first to the lowest, then to the highest possible position depends very little on the velocity of the airstream.

For  $\pm 10.25^\circ$  in the blades we measure  $\pm 9.5^\circ$  by the silk thread.

For  $\pm 23.1^\circ$  in the blades we measure  $\pm 20.5^\circ$  by the silk thread.

At rest, the angle of deviation of the airstream is thus equal to 0.91 of the angle of deviation of the blades.

From this we conclude that for  $\pm 16.75^\circ$  in the blades we shall have  $\pm 15.2^\circ$  in the airstream.

2. Variations of amplitude with rate of oscillation.

For the same velocity of the airstream ( $V = 26.3 \text{ m} = 86.29 \text{ ft./sec.}$ ) we measured the following amplitudes:

Amplitude of blades =  $\pm 10.25^\circ$

	Rate of oscillation	Amplitude of stream
$V = 26.3 \text{ m (86.29 ft.)/sec.}$	{ 1 per sec.	$\pm 8.25^\circ$
	{ 6 " "	$\pm 8.25^\circ$
	{ 10 " "	$\pm 11.5^\circ$

For amplitude of blades =  $\pm 23.1$

	Rate of oscillation	Amplitude of stream
$V = 24.8 \text{ m (81.36 ft.)}/\text{sec.}$	{ 1 per sec.	$\pm 18.5^{\circ}$
	{ 6 " "	$\pm 17.0^{\circ}$

For amplitude of blades =  $\pm 16.75^{\circ}$

	Rate of oscillation	Amplitude of stream
$V = 26.3 \text{ m (86.29 ft.)}/\text{sec.}$	( 6 per sec.	$\pm 12.75^{\circ}$

These results are plotted in Figs. 10 and 11 where we see that the amplitude of the wind first decreases when the blades are moving slowly and increases with the increase of the rate of oscillation.

For the same speed of oscillation and the same velocity of the wind, the amplitude of the airstream is still proportional to the amplitude of the blades but the degree of proportion depends on the number of oscillations per second.

For instance, for 6 oscillations per second and a speed of 26 m (85.3 ft.) the amplitude of the airstream is equal to 0.78 of the amplitude of the blades.

### 3. Variation of amplitude with the speed of the airstream.

For the same amplitude of blades ( $\pm 10.25^{\circ}$ ) and at the same speed of oscillation we measured the following amplitudes in function of the velocity  $V$  of the airstream,

## 10 oscillations per second

V =	35.43 ft. 10.80 m	48.23 ft. 14.7 m	68.24 ft. 20.80 m	76.77 ft. 23.40 m	86.12 ft. 26.25 m
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Amplitude = $\pm 14.5^\circ$	$\pm 12.0^\circ$	$\pm 11.5^\circ$	$\pm 11.5^\circ$	$\pm 11.5^\circ$
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## 6 oscillations per second.

V =	29.53 ft. 9.00 m	41.83 ft. 12.75 m	58.07 ft. 17.7 m	74.47 ft. 22.7 m	86.29 ft. 26.30 m
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Amplitude = $\pm 9.25^\circ$	$\pm 8.25^\circ$	$\pm 8.25^\circ$	$\pm 8^\circ$	$\pm 8.25^\circ$
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## 1 oscillation per second.

V =	36.75 ft. 11.2 m	53.31 ft. 16.25 m	68.24 ft. 20.8 m	78.41 ft. 23.9 m	86.94 ft. 26.5 m
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Amplitude = $\pm 8^\circ$	$\pm 9^\circ$	$\pm 9.5^\circ$	$\pm 9^\circ$	$\pm 8.5^\circ$
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These results are plotted in Fig. 11. We see that at speeds  $V$  greater than 15 m (49.2 ft.)/sec. the amplitude of the airstream varies little and has always a slight tendency to diminish as  $V$  increases.

But for low speeds  $V$ , those of the order of magnitude of the number of oscillations per second, the amplitude of the stream increases rather rapidly as the speed decreases; a similar result was found for a blade amplitude of  $\pm 16.75^\circ$  or  $\pm 23.1^\circ$ .

NOTE.-- We see that the values of the amplitude measured by the silk thread by the latter method are slightly lower than those obtained with the silk thread and photography. We think that the measurements last given are more accurate than the former because the thread was very short and had therefore very little inertia.

Some inertia did, however, remain and we cannot positively affirm that the amplitude of oscillation of the air was quite accurately reproduced by the thread.

(c) Experiments with strips of silk.-- A strip of very light<sup>silk</sup> 2 m (78.74 in.) long and 10 cm (3.94 in.) wide was exposed to the action of the oscillating airstream. Observing the strip through a stroboscope, we saw that it described regular undulations corresponding pretty closely to the actual undulations of the airstream.

Such strips, examined through a kinetoscope or stroboscope would thus seem very convenient for studying the vertical undulations of the wind.

Determination of the position of the blades for obtaining  
a horizontal airstream.

Before beginning to measure the speeds, we had to set up a horizontal airstream with the blades at rest.

For this purpose we applied the method of inverting the wing. We first tried with a symmetrical biconvex wing (SC 173) but found a simple convex wing (SC 116) more satisfactory since the angles of attack could be measured with greater facility and accuracy.

The results of these tests are given in Table IV and plotted in Fig. 3.

We see that the blade position corresponding to a horizontal airstream will be characterized by an angle of  $-0.2^{\circ}$  at lever No. 4, chosen as reference. We also note that the blades had to be turned by an angle practically equal to the deviation to be obtained. This confirms the previous data on the relation between the amplitude of the blade movements and the amplitude of the oscillations of the airstream.

In our experiments these amplitudes are practically the same, while in Katzmayer's the amplitude of the airstream oscillations was about half that of the blade oscillations. We believe that this difference of results is due to the fact that Katzmayer employed a very small number of blades while we have a great many and they affect the airstream in almost its entire height.

Experiments with a Supporting Wing.

The experiments were made with the wing SC 100 (S.T.Ae. No. 17 A). The dimensions of the model were 720 x 120 mm (28.3 x 4.72 in.) with an aspect ratio of 6. A parallelogram balance was used and the wing was suspended by wires.

Speed of airstream = 30 m (98.4 ft.) per sec.

(a) Effect of the presence of fixed blades.-- The blades being placed in the position for obtaining a horizontal airstream, the polar curve of the wing SC 100 was determined in the usual way.

The results are given in Table V, and plotted in Fig. 4 and 5. On the same plates are plotted the results relative to the same wing in the absence of blades. (Results extracted from Bulletin S.T.Ae. No. 12.)

In Fig. 4 we see that the unit curves  $C_L$  are almost if not quite unaffected by the presence of blades. The very slight difference between these curves is of the order of magnitude of experimental tests for the measurement of angles ( $\pm 0.2^\circ$ ). As regards the  $C_D$ , the unit curves have the same sweep, but that given by the experiments in presence of blades is constantly above the other. This should preferably be attributed to the influence of the characteristic product  $V \times b$  which is 5 square meters (55.97 square feet) per second in one case, and 3.7 square meters (39.83 square feet) per second in the other. The polar curves shown in Fig. 5 evidently present the same stagger and the same sweep.



Lastly, in Table VI we give the results relating to the same wing for a much lower wind velocity.

This velocity reaches a mean value of only 9.30 m, that is,  $V \times b = 1.15 \text{ sq.m (12.38 sq.ft.)}$  per sec. In this experiment a very small arch of the tunnel was used as a support, the wing being attached to it by means of fork joints and small rods. The influence of this support is certainly negligible.

These results are plotted in Figs. 4 and 5. In Fig. 4 we see that the  $C_L$  curves corresponding to a given angle are weaker than the normal  $C_L$  curves. This again must be imputed to the influence of  $Vb$ .

As a matter of fact, we know that the  $C_L$  curves obtained for  $Vb$  of less than 2 sq.m (21.53 sq.ft.) per sec., are weaker than those for a velocity greater than 2 sq.m per sec.

The effect on the  $C_D$  curves is still more marked, especially for low lifts.

Briefly, the effect of the presence of blades can not be clearly demonstrated by these experiments, because it is linked up with the effect of the velocity. We may, however, say that the influence of the blades should be almost, if not entirely negligible at velocities greater than 3.5 sq.m (37.67 sq.ft.) per sec.

(b) Effect of the blades in oscillation. Katzmayer effect.

1st series of experiments.

In Tables VII, VIII, and IX, we give the results plotted in Figs. 6 and 7 which are obtained by making the blades oscillate

with a mean amplitude of  $\pm 10^\circ$  and at rates of 1.17, 6 and 11 oscillations per second.

Mean speed of airstream = 26 m (85.3 ft.) per second.

For these measurements the balance was fitted with an adjustable dashpot for damping the oscillations.

The results obtained are represented in Figs. 6 and 7, which also give the unitary curves and the polar curve of the wing, when the blades are at rest and horizontal. It is obvious that the unitary curves  $C_L$  approach the normal curve more closely as the oscillation number increases.

The unitary curves  $C_D$  well illustrate the Katzmayer effect with negative resistances over a considerable range of angles of attack. An increase in the oscillation number appears to have a favorable effect.

In any event, there is occasion to note that the amplitude of oscillation of the airstream (measured by the silk thread) increases slightly with the number of oscillations. Under these conditions, the improvement in the polar curves with the increase in the oscillation may be imputed in part to the correlative increase in the amplitude of oscillation.

#### 2nd Series of Experiments.

A second series of experiments at a very low velocity of the air was made with the same wing. The object of this decrease of velocity was to discover whether a notable decrease in the wave length of the oscillating wind affected the results. Experiments were made at a mean velocity of 9.30 me-

ters; the corresponding wave lengths at 1, 6 and 10 oscillations per second were respectively 9.30 m (30.51 ft.), 1.55 m (5.09 ft.), and 0.90 m (2.95 ft.).

For these tests the model was supported by a rigid wall support as previously described.

The results obtained are given in Tables X, XI, and XII. They are plotted in Figs. 8 and 9, and compared with the corresponding polar curve in presence of fixed blades.

We see that these results confirm those previously obtained as regards the Katzmayer effect. The best results, however, are obtained with the shortest wave length. That is doubtless because in this case the amplitude of oscillation of the airstream is greatly increased ( $\pm 16.5^\circ$  has been measured on the silk thread). Thus the effect of wave length can not be quite clearly evolved from these tests.

### 3rd Series of Experiments.

Effect of the Amplitude of Oscillation.— On the same wing SC 100 we studied the effect of the amplitude of oscillation for a rate of 6 oscillations per second and amplitudes of the airstream equal respectively to  $\pm 12.75^\circ$  and  $\pm 17^\circ$ .

The results obtained are given in Tables XIII and XIV and plotted in Figs 10, 11, 12 and 13.

We see that as amplitude increases the unit curves  $C_L$  are more and more inclined. Or, in other words, when the  $C_L$  curve is greater than .2, the lift for a given angle of attack tends to

decrease as amplitude increases. For  $C_L$  curves less than .3, the phenomenon is reversed.

As regards the  $C_D$  curves we see that the reduction increases with the amplitude. In Fig. 12 are plotted the variations of the minimum  $C_D$  curve in function of the amplitude of oscillation. The representative curve has a sinusoidal sweep and would doubtless reach a minimum for an amplitude slightly higher than  $\pm 20^\circ$ .

Lastly, in Fig. 13 we see that the polar curves sweep more and more to the left as the amplitude increases.

#### Discussion of Results.

We may characterize the intensity of the Katzmayr effect by the variations  $\Delta C_D$  and  $\Delta C_L$  measured on the unit curves with respect to the same curves without oscillation of the airstream.

We may also characterize the intensity of the Katzmayr effect by the variations  $\Delta C_D$  measures on the polar curves for one single  $C_L$  curve. We should add the corresponding variations  $\Delta \alpha$  for the angle of attack.

Thus in Fig. 13 we have plotted the variations of  $\Delta C_D$  in function of  $C_L$  for the various amplitudes of the stream. Starting from these curves we have noted the variations of  $\Delta C_D$  for the same  $C_L$  curve in function of the amplitude of the stream. These variations are plotted in Fig. 14. Fig. 15 shows the same variations referred to the amplitude of oscillation of the blades.

We may utilize the group of curves in Fig. 14 for taking into account the effect of the increase of amplitude of the airstream in experiments concerning the effect of the speed of oscillation. (See Figs. 7, 8 and 9.)

In Fig. 7 we have the results relative to one and the same blade amplitude  $\pm 10.25^\circ$  with rates of oscillation varying from 1 to 11 per second. From Figs. 10 and 11 we see that the true amplitudes of the airstream were:

For 1.17 osc. per sec.	Amplitude by silk thread =	$\pm 8.5^\circ$
" 6 " " " " " "	" " " " " "	= $\pm 8.3^\circ$
" 11 " " " " " "	" " " " " "	= $\pm 12.0^\circ$

The polar curves (1) and (6) referring to speeds 1 and 6 are very near together, chiefly for the  $C_L$  curves lower than 50 or 55. From the above table we see that the true amplitude is also the same.

On the contrary, for the polar curve (11) referring to the speed 11, a correction must be made to bring it to amplitude  $\pm 8.5$ , taking into account the  $C_D$  curves of Figs. 14 and 15.

Obviously, these corrections are empirical and implicitly assume that the effect of amplitude of oscillation is algebraically added to the effect of wave length.

Still, in applying these corrections within the limit of the values of  $C_L$  for which the curves in Figs. 14 and 15 have a regular sweep, we find that the polar curve (11) of Fig. 7 would be notably shifted to the right. A similar result is obtained with

the polar curve (10), Figs. 8 and 9.

If we admit that such corrections are allowable, we must conclude that the effect of the increase of rate of oscillation, or rather, the effect of the decrease of wave length in the airstream, results in considerable attenuation of the intensity of the Katzmayer effect.

This consideration is particularly important in seeking the Katzmayer effect in a natural wind. In point of fact, we think that if the wind has degrees of oscillation in the vertical plane, the Katzmayer effect must show itself frequently on airplanes flying in a high wind. But our personal observation has never led us to note such a phenomenon. (We are referring here to the numerous and permanent notes made of airplane performances during the war.)

It would seem, however, that the wind must possess this degree of liberty in the vertical plane, but only at an altitude at which the influence of the ground is negligible.

It seems to us logical to suppose that the manifestation of the Katzmayer effect on ordinary airplanes is due to the fact that the wave lengths of the natural wind are probably too short for the normal chords of the wings of these airplanes.

In spite of the uncertainty which subsists, it does not seem impossible that such is the case. And therefore the Katzmayer effect in the natural wind should be sought preferably on narrow surfaces.

With this object in view, we have equipped a special aerodynamic balance with which we shall seek the Katzmayer effect in a natural wind.

#### 4th Series of Experiments.

We also experimented with a model wing SC No. 6, with the object of bringing out the effect of wave length. The profile of this wing is given in Fig. 16. Its dimensions were:

b, Span .....0.600 m (1.97 ft.)

l, Chord .....0.443 m (1.45 ft.)

S, Area .....0.265 sq.m (2.85 sq.ft.)

b/l, Aspect ratio .....1.36

The chord 0.443 m (1.45 ft.), being very large, we hoped that the effect of the decrease in wave length would be more clearly shown than with the wing SC 100, the chord of which was about four times smaller.

The first experiments with the wing SC No. 6, were made with the usual wire balance.

The results are given in Tables XIX, XX, XXI, and XXII, and are plotted in Figs. 17 and 18.

Experiments on air velocity of 26 m (85.3 ft.) and 15.30 m (50.2 ft.) per second were carried out at the same rate of oscillation (6 per second). The corresponding wave lengths were  $\frac{26}{6} = 4.35$  m (14.27 ft.) and  $\frac{15.5}{6} = 2.55$  m (8.37 ft.).

In Figs. 17 and 18 we see that the unit curves and polar curves are absolutely coincident.

We then tried with an airspeed of 15.30 m (50.3 ft.) and at rates of oscillation of 1.27 and 10.6 per second.

In Figs. 17 and 18 we see that the unit curves and the polar curve at 10.6 oscillations coincide with those at 6.

Only the unit curves and the polar curve at 1.27 oscillations differ from the above.

A second set of experiments were made with the same SC No. 6 wing, utilizing the simplified wall support previously described.

The airspeed was about 6 m (19.68 ft.) per second and we utilized the three rates of oscillation corresponding approximately to wave lengths  $\frac{6}{1.27} = 4.75$  m (15.58 ft.),  $\frac{6}{6} = 1.00$  m (3.28 ft.) and  $\frac{6}{10.6} = 0.57$  m (1.87 ft.)

The results are tabulated in Tables XV, XVI, XVII and XVIII, of Fig. 16. Table XV corresponds to the unit curves and the polar curve of the wing SC No. 6 on its support, in presence of horizontal and fixed blades.

These results are plotted in Figs. 19 and 20. We see that the polar curves improve as the number of oscillations increases.

This result is again contrary to what we had assumed respecting the effect of wave length.

But as we previously remarked, in the whole of these experiments we had to consider the double effect of wave length and of



the increase of amplitude of oscillation.

In Fig. 11 we see that for an airspeed  $V$ , of 15 m (49.2 ft.), the amplitudes of oscillation should be approximately as follows:

Rate of oscillation = 1 per second.	Amplitude $\pm 9.5^\circ$
" " " = 6 " "	" $\pm 8.25^\circ$
" " " = 10 " "	" $\pm 12.00^\circ$

Under these conditions we can understand that the effect of decrease of wave length from 12 m (39.37 ft.) to 1.44 m (4.72 ft.), may have been hidden by the effect of the correlative increase in amplitude of oscillation from  $8.25^\circ$  to  $12^\circ$ .

These same curves (Fig. 11) do not enable us to determine the amplitudes corresponding to tests at 6 m (19.7 ft.) per second. The sweep of these curves shows, however, that the increase of amplitude for 6 and 10 oscillations per second is still more marked at this low speed of the air. We can thus understand why the polar curves in Fig. 20 (SC No. 6) fall in a similar way to those found when investigating the effect of amplitude, completely hiding the effect of the decrease of wave length.

In later experiments we shall doubtless be able to separate clearly these two effects.

Translated from the French  
by Paris Office,  
National Advisory Committee  
for Aeronautics.

## NUMERICAL TABLES OF RESULTS.

Table I - Distribution of speed along a horizontal diameter.

Ref. Marks	0 d	1 d	2 d	3 d	4 d	5 d	6 d
$H_s$	70.9	70.0	70.0	70.35	70.9	71.15	70.85
Standard Pitot tube }	72.1	74.5	74.25	74.0	75.0	76.15	72.5
$\frac{P_e}{H_s}$	1.016	1.064	1.06	1.051	1.058	1.056	1.022
	(a)						
Ref. Marks	0 g	1 g	2 g	3 g	4 g	5 g	6 g
$H_s$	69.2	70.55	70.8	71.1	71.0	71.75	70.9
Standard Pitot tube }	73.6	75.1	45.7	75.5	76.0	76.85	76.1
$\frac{P_e}{H_s}$	1.063	1.063	0.645	1.061	1.07	1.071	1.073
			(b)				

Experiment made July 15. (a) Pitot tube to rear of forward bolt. (b) Pitot tube to rear of attachment fitting. (g)

Table II - Variations of  $\frac{P_e}{H_s}$  at point 1 d in function of speed.

(a) Blades horizontal and without oscillation.

Ref. Marks	0 d	1 d	2 d	3 d	4 d	5 d	6 d
$H_s$	48.9	50.9	53.4	58.8	66.8	70.0	70.5
$P_e$	51.6	53.6	56.3	62.2	70.2	73.8	74.6
$\frac{P_e}{H_s}$	1.054	1.052	1.054	1.057	1.05	1.055	1.055

(b) Blade oscillation : 6 per second.

Ref. Marks	3 g	4 g	5 g	6 g			
$H_s$	48.7	53.1	59.8	67.0	73.2		
$P_e$	53.2	57.7	65.5	73.2	80.0		
$\frac{P_e}{H_s}$	1.093	1.087	1.095	1.091	1.092	mean = 1.092	

Table II Cont. - Same study with adjustable Pitot tube.

(a') Blades horizontal and without oscillation.

Ref. Marks	0 d	1 d	2 d	3 d	4 d	5 d	6 d
H <sub>s</sub>	46.5	49.9	54	56.2	55.6	61.3	64.3
P <sub>e</sub>	45.0	48.4	52.3	54.6	56.8	59.2	62.3
$\frac{P_e}{H_s}$	0.968	0.97	0.97	0.972	0.971	0.975	0.969
	Mean = 0.970						

(b') Blade oscillation : 6 per second.

Ref. Marks	1 g	2 g	3 g	4 g	5 g	6 g
H <sub>s</sub>	46.8	50.9	55.5	59.8	67.0	67.3
P <sub>e</sub>	46.2	50.0	54.8	59.5	67.0	67.2
$\frac{P_e}{H_s}$	0.987	0.982	0.987	0.995	1.00	0.998
	Mean = 0.995					

Table III - Same study with pneumometer.

(a) Blades horizontal and without oscillation.

Ref. Marks	0 d	1 d	2 d	3 d	4 d	5 d
H <sub>s</sub>	48.2	52.5	56.7	61.8	65.4	68.2
P <sub>n</sub>	71.0	78.0	83.7	92.0	97.3	101.5
$\frac{P_n}{H_s}$	1.474	1.485	1.476	1.489	1.482	1.489
	Mean = 1.486					

(b) Blade oscillation : 6 per second.

Ref. Marks	1 g	2 g	3 g	4 g	5 g	6 g
H <sub>s</sub>	50.0	53.2	55.4	59.2	63.3	67.0
P <sub>n</sub>	76.0	81.0	84.5	90.0	96.5	102.0
$\frac{P_n}{H_s}$	1.52	1.522	1.525	1.52	1.524	1.522
	Mean - 1.522					

Table IV - Investigation on blade position required for horizontal airstream.

(Reference adopted = control lever of a median blade.)

(a) Lever No.4 inclined at  $-1^{\circ}$ .

Angles	$-7^{\circ}$	$-4.05^{\circ}$	$-1^{\circ}$	$+2.05^{\circ}$	} Normal position
$H_s$	67	66.2	66.8	66	
P	-220	+660	1640	2600	
$\frac{P}{H_s}$	-3.28	+10	24.55	39.4	
Angles	$-8.1^{\circ}$	$-5.1^{\circ}$	$-2.1^{\circ}$	$+1.05^{\circ}$	} Inverted position
$H_s$	68.5	67.5	68.5	69.5	
P	180	-710	-1730	-2810	
$\frac{P}{H_s}$	2.63	-10.50	-25.25	-40.4	

Conclusions: Difference  $-1.2^{\circ}$  = stream descending by  $0.6^{\circ}$

(b) Lever No.4 inclined at  $-0.5^{\circ}$ .

Angles	$-8.1^{\circ}$	$-5.1^{\circ}$	$-2.1^{\circ}$	$+1.05^{\circ}$	} Inverted position
$H_s$	70	71.4	72	72.5	
P	280	-640	1695	-2800	
$\frac{P}{H_s}$	4.0	-8.96	-23.5	-38.55	

Conclusions: Difference  $-0.5^{\circ}$  = stream descending by  $2.5^{\circ}$ .

(c) Lever No.4 horizontal ( $0^{\circ}$ )

Angles	$-8.1$	$-5.1$	$-2.1$	$-2.1$	} Inverted position
$H_s$	72.5	73	73.5	73.5	
P	410	-510	-1565	-2650	
$\frac{P}{H_s}$	5.65	-7	-21.25	-36.3	

Conclusions: Difference  $+3.8^{\circ}$  = stream ascending by  $1.9^{\circ}$ .

## STUDIES ON KATZMAYR EFFECT. NUMERICAL TABLES.

Table V - Polar curve of wing SC 100 in presence of fixed blades.

$\alpha$	$-11.5^\circ$	$-8.5^\circ$	$-5.75^\circ$	$2.8^\circ$	$0.0^\circ$	$3^\circ$
$C_L$	-.157	.06	.279	.496	.719	.921
$C_D$	.019	.0157	.0186	.0267	.04214	.0593
$\alpha$	$6.0^\circ$	$8.8^\circ$	$11.9^\circ$	$14.9^\circ$	$16.9^\circ$	
$C_L$	1.098	1.26	1.37	1.412	1.328	
$C_D$	.0625	.115	.1508	.1964	.2493	

Experiment on wire balance  
 $V = 30$  m (98.4 ft.) per second.  
 $Vb = 3.7$  sq.m (39.83 sq.ft.) per second.

Table VI - Another polar curve in presence of blades.

$\alpha$	$-11.55^\circ$	$-8.20^\circ$	$-5.0^\circ$	$-2.20^\circ$	$+1.80^\circ$	$4.45^\circ$	$8^\circ$
$C_L$	.147	+.0565	.264	.42	.684	.916	.01117
$C_D$	.147	.0493	.0455	.05	.0525	.0763	.1047

Speed = 9.30 m (30.51 ft.)  
 $Vb = 1.15$  sq.m (12.38 sq.ft.) per second.  
 Experiment made with roof support.

Results with oscillating blades (mean amplitude  $\pm 10^\circ$ ).

Table VII - Polar curve of SC 100-Rate of oscillation 1.17 per second (70 per minute). Mean velocity 26.40 m(86.6 ft.)

$\alpha$	$-11.5^\circ$	$-8.5^\circ$	$-5.8^\circ$	$-2.8^\circ$	$+0.05^\circ$
$C_L$	-.048	+.096	.278	.489	.673
$C_D$	+.0271	-.00736	-.0178	-.0093	+.0046
$\alpha$	$3.00^\circ$	$6.00^\circ$	$8.87^\circ$	$11.95^\circ$	$14.95^\circ$
$C_L$	.855	.993	1.075	1.137	1.17
$C_D$	+.0275	.0524	.1046	.1556	.229

Table VIII - Polar curve of SC 100 - Rate of oscillation 6 per sec.  
(360 per minute) Mean velocity 25.90 m (84.97 ft.)

$\alpha$	$-11.5^\circ$	$-8.5^\circ$	$-5.75^\circ$	$-2.8^\circ$	$+0.05^\circ$
$C_L$	-.0615	+.068	.282	.515	.72
$C_D$	+.0257	-.0126	-.016	-.0083	+.0062
$\alpha$	$3.00^\circ$	$6.00^\circ$	$8.85^\circ$	$11.95^\circ$	
$C_L$	.873	1.03	1.135	1.185	
$C_D$	.0284	.0543	.0985	.1471	

Table IX - Polar curve of SC 100 - Rate of oscillation 11 per sec.  
(660 per minute) Mean velocity 25.30 m (83 ft.).

$\alpha$	$-10.5^\circ$	$-7.75^\circ$	$-4.8^\circ$	$-1.9^\circ$	$+1.05^\circ$
$C_L$	-.0714	+.119	.358	.576	.77
$C_D$	+.0287	-.0148	-.0210	-.0105	+.0045
$\alpha$	$3.95^\circ$	$6.90^\circ$	$9.75^\circ$	$12.70^\circ$	
$C_L$	.946	1.08	1.20	1.28	
$C_D$	.0350	.0586	.0930	.1598	

Table X - Polar curve of SC 100 - Rate of oscillation 1 per sec.

$\alpha$	$-11.5^\circ$	$-8.3^\circ$	$-5.0^\circ$	$-2.3^\circ$	$+1.2^\circ$
$C_L$	.038	+.109	.382	.423	.646
$C_D$	.0552	.0185	.0016(?)	.0131	.0262
$\alpha$	$4.43^\circ$	$8.0^\circ$	Mean velocity 9.30 m (30.51 ft.)		
$C_L$	.813	.945	Wave length 9.30 m (30.51 ft.)		
$C_D$	.0422	.0839	Amplitude of stream $\pm 10.5$		

Table XI - Polar curve of SC 100 - Rate of oscillation 6 per sec.

$\alpha$	$-11.5^\circ$	$-8.2^\circ$	$-5.0^\circ$	$-2.3^\circ$	$+1.2^\circ$
$C_L$	-.11	+.102	+.30	.457	.65
$C_D$	.0403	.0123	.0074	.0146	.0239
$\alpha$	$4.43^\circ$	$8.0^\circ$	Mean velocity 9.30 m (30.51 ft.)		
$C_L$	.84	1.005	Wave length 1.55 m (5.09 ft.)		
$C_D$	.0446	.0867	Amplitude of stream $\pm 10.5$		

Table XII - Polar curve of SC 100 - Rate of oscillation 10 per sec.

$\alpha$	-11.5	-8.2	-5.0	-2.2	+1.2
$C_L$	-.119	+.1165	.308	.470	.66
$C_D$	.0338	+.00047	.0118	.00434	+.0071
$\alpha$	4.43	8.0	Mean velocity 9 m (29.53 ft.)		
$C_L$	.85	.985	Wave length 0.90 m (2.95 ft.)		
$C_D$	.0205	.0538	Amplitude of stream $\pm 16.5^\circ$		

Table XIII - Velocity 6 osc.      Amplitude  $\pm 12.75^\circ$ 

$\alpha$	-13.3 $^\circ$	-10.3 $^\circ$	-7.34 $^\circ$	-4.37 $^\circ$	-1.41
$C_L$	-.119	+.0408	.179	.314	.503
$C_D$	.0551	.0147	.01732	.0489	.0475
$\alpha$	+ 1.55 $^\circ$	4.52 $^\circ$	7.49 $^\circ$	10.17 $^\circ$	
$C_L$	.692	.832	.96	1.07	
$C_D$	.0247	.0116	.0576	.1267	

Table XIV - Velocity 6 osc.      Amplitude  $\pm 17^\circ$ 

$\alpha$	-10.4 $^\circ$	-7.41 $^\circ$	-4.46 $^\circ$	1.50 $^\circ$	1.57 $^\circ$
$C_L$	.024	.175	.3075	.463	.612
$C_D$	.0047	.0483	.07036	.0738	.0604
$\alpha$	4.44 $^\circ$	7.40 $^\circ$	10.5 $^\circ$	13.25 $^\circ$	
$C_L$	.763	.908	1.037	1.173	
$C_D$	.0257	.0383	.0274	.2128	

STUDY OF KATZMAYR EFFECT. ABSOLUTE COEFFICIENT OF  
POLAR CURVES OF WING SC-6.

Velocity of wind : 6 m (19.68 ft.) per sec.  $V \times b = 3.6$  sq.m (38.75  
sq.ft./sec.)

$b = 0.600$  m (1.97 ft.)  $b/l = 1.36$

$l = 0.442$  m (1.45 ft.)

Area : 0.2650 sq.m (2.85 sq.ft.)

Profile and table of ordinates are given in Fig. 16.

Table XV - I. Blades Immobile

$\alpha$	$-7.6^\circ$	$-4.5^\circ$	$-1.4^\circ$	$2.1^\circ$	$5.3^\circ$	$8.9^\circ$	$12.15^\circ$	$15.4^\circ$
$C_L$	-.0078	.126	.227	.348	.452	.595	.734	.831
$C_D$	.0271	.0251	.0304	.0478	.0645	.1035	.1425	.1887

Table XVI - II. With Oscillating Blades.  
Rate of oscillation: 1 per sec.

$\alpha$	$-7.6^\circ$	$-4.5^\circ$	$-1.4^\circ$	$2.1^\circ$	$5.3^\circ$	$8.9^\circ$	$12.15^\circ$	$15.4^\circ$
$C_L$	-.0197	.1125	.209	.329	.443	.566	.684	.778
$C_D$	.0416	.0257	.0243	.0366	.0543	.0871	.1258	.1833

Table XVII - Rate of oscillation : 6 per sec.

$\alpha$	$-7.6^\circ$	$-4.5^\circ$	$-1.4^\circ$	$2.1^\circ$	$5.3^\circ$	$8.9^\circ$	$12.15^\circ$	$15.4^\circ$
$C_L$	-.026	.1197	.2278	.3344	.468	.591	.715	.82
$C_D$	.0346	.0210	.0233	.0360	.0560	.0944	.1338	.188

Table XVIII - Rate of oscillation : 11 per sec.

$\alpha$	$-7.6^\circ$	$-4.5^\circ$	$-1.4^\circ$	$2.1^\circ$	$5.3^\circ$	$8.9^\circ$	$12.15^\circ$	$15.4^\circ$
$C_L$	-.045	.1058	.2023	.344	.466	.591	.714	.824
$C_D$	.0382	.0179	.0179	.0252	.0504	.0873	.126	.1814



## EFFECT OF WAVE LENGTH

## POLAR CURVES OF WING SC-8 OBTAINED WITH WIRE BALANCE.

Table XIX - Rate of oscillation : 6 per second.

Velocity of wind : 26 m (85.3 ft.) per sec.

$\alpha$	$-7.7^\circ$	$-4.95^\circ$	$-1.80^\circ$	$1.10^\circ$	$4^\circ$	$6.95^\circ$	$9.75^\circ$	$12.70^\circ$	$15.65^\circ$
$C_L$	.015	.093	.2075	.320	.408	.536	.648	.754	.85
$C_D$	.0345	.0206	.0175	.0259	.0432	.07	.1026	.143	.1944

Table XX - Rate of oscillation : 6 per second.

Velocity of wind : 15 m (49.2 ft.) per sec.

$\alpha$	$-7.7^\circ$	$-4.95^\circ$	$1.85^\circ$	$1.10^\circ$	$3.95^\circ$	$6.95^\circ$
$C_L$	.0074	.1050	.215	.329	.441	.54
$C_D$	.0343	.0210	.0182	.0273	.0452	.0616

$\alpha$	$9.75^\circ$	$12.70^\circ$	$15.65^\circ$	$18.50^\circ$
$C_L$	.643	.769	.851	.937
$C_D$	.1023	.1473	.1934	.2558

Table XXI - Rate of oscillation : 1.27 per second.

Velocity of wind : 15 m (49.2 ft.) per sec.

$\alpha$	$-7.7^\circ$	$-4.95^\circ$	$-1.80^\circ$	$1.10^\circ$	$3.95^\circ$	$6.95^\circ$
$C_L$	.0142	.090	.205	.303	.412	.511
$C_D$	.0364	.0222	.0203	.0273	.0426	.0660

$\alpha$	$9.80^\circ$	$12.70^\circ$	$15.65^\circ$	$18.55^\circ$
$C_L$	.61	.729	.81	.086
$C_D$	.0988	.1434	.1911	.2652

Table XXII - Rate of oscillation : 11 per sec.

Velocity of wind : 15 m (49.2 ft. per sec.

$\alpha$	$-7.7^\circ$	$-4.95^\circ$	$-1.85^\circ$	$1.10^\circ$	$3.95^\circ$	$6.95^\circ$
$C_L$	.0232	.095	.2165	.306	.438	.535
$C_D$	.0353	.0209	.0194	.0271	.0460	.0780

$\alpha$	$9.75^\circ$	$12.70^\circ$	$15.64^\circ$	$18.50^\circ$
$C_L$	.66	.763	.86	.95
$C_D$	.1057	.1479	.1992	.2585

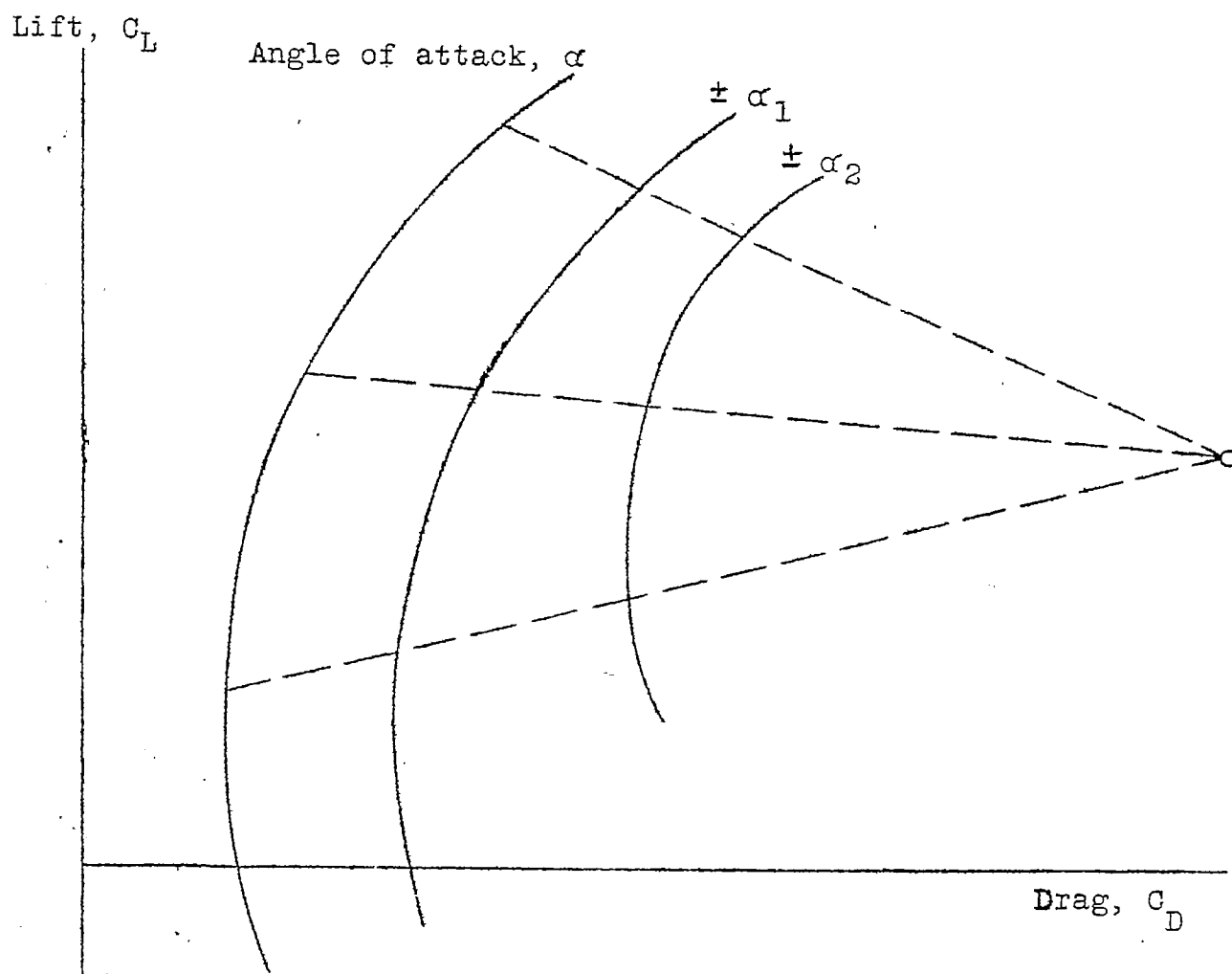
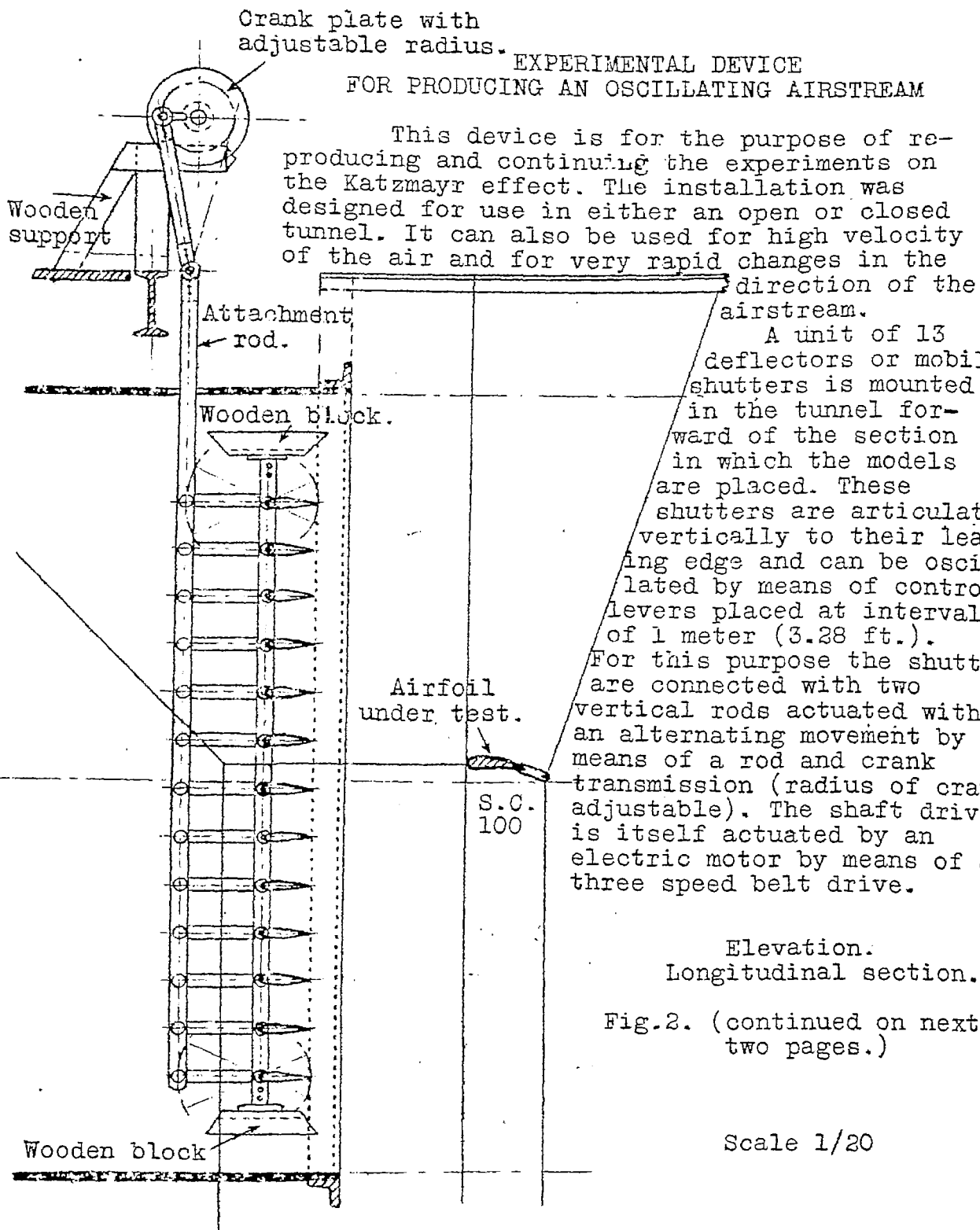
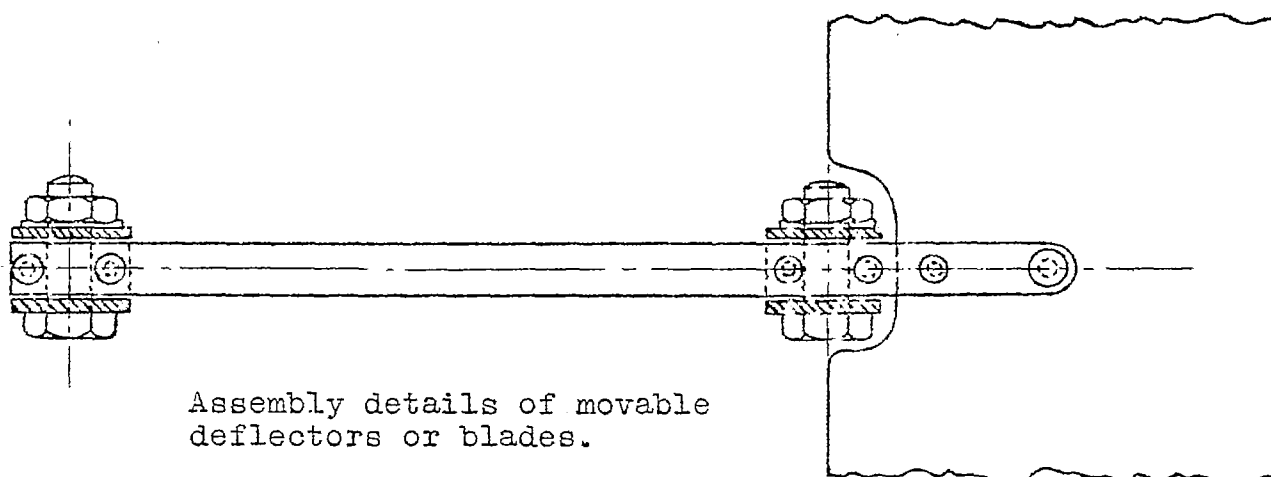
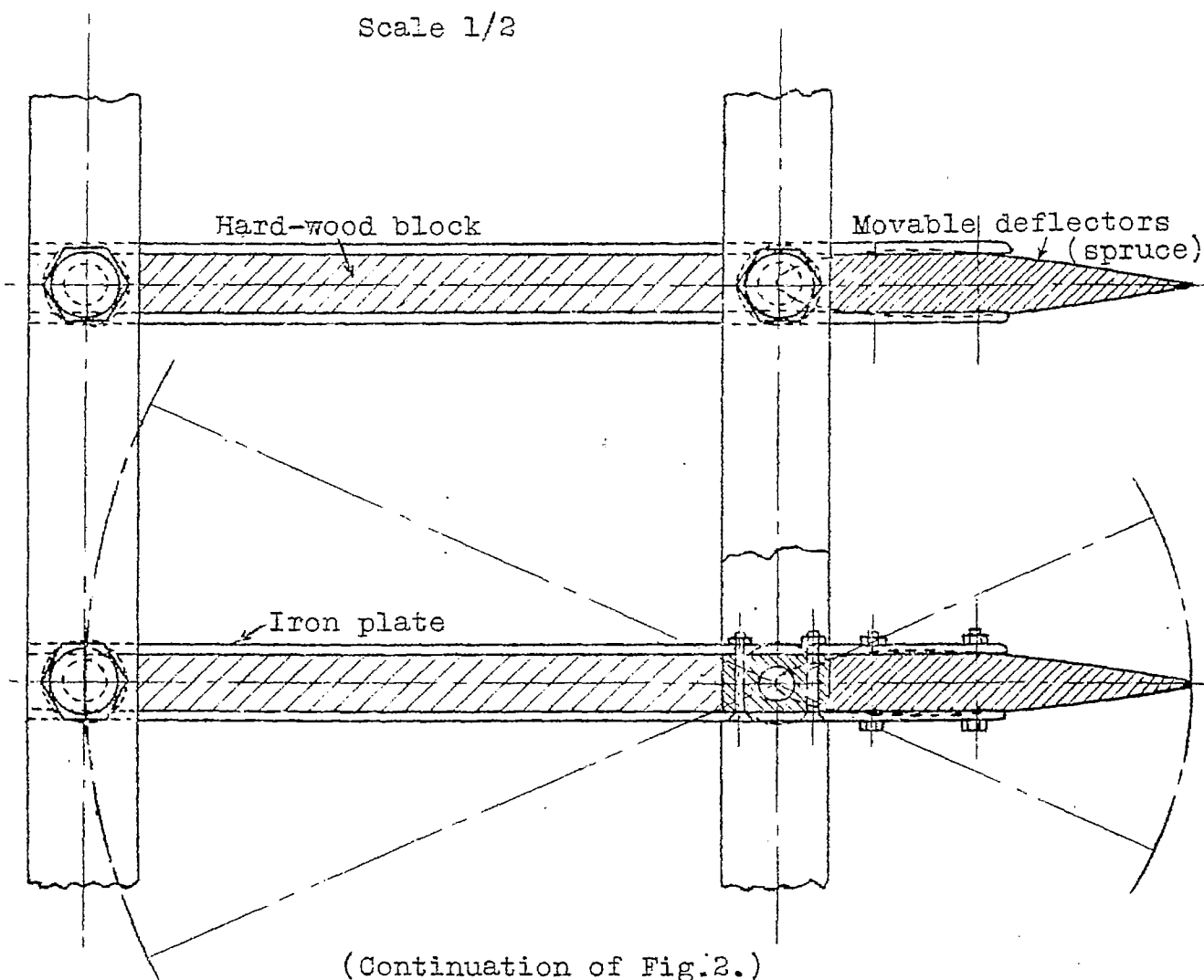


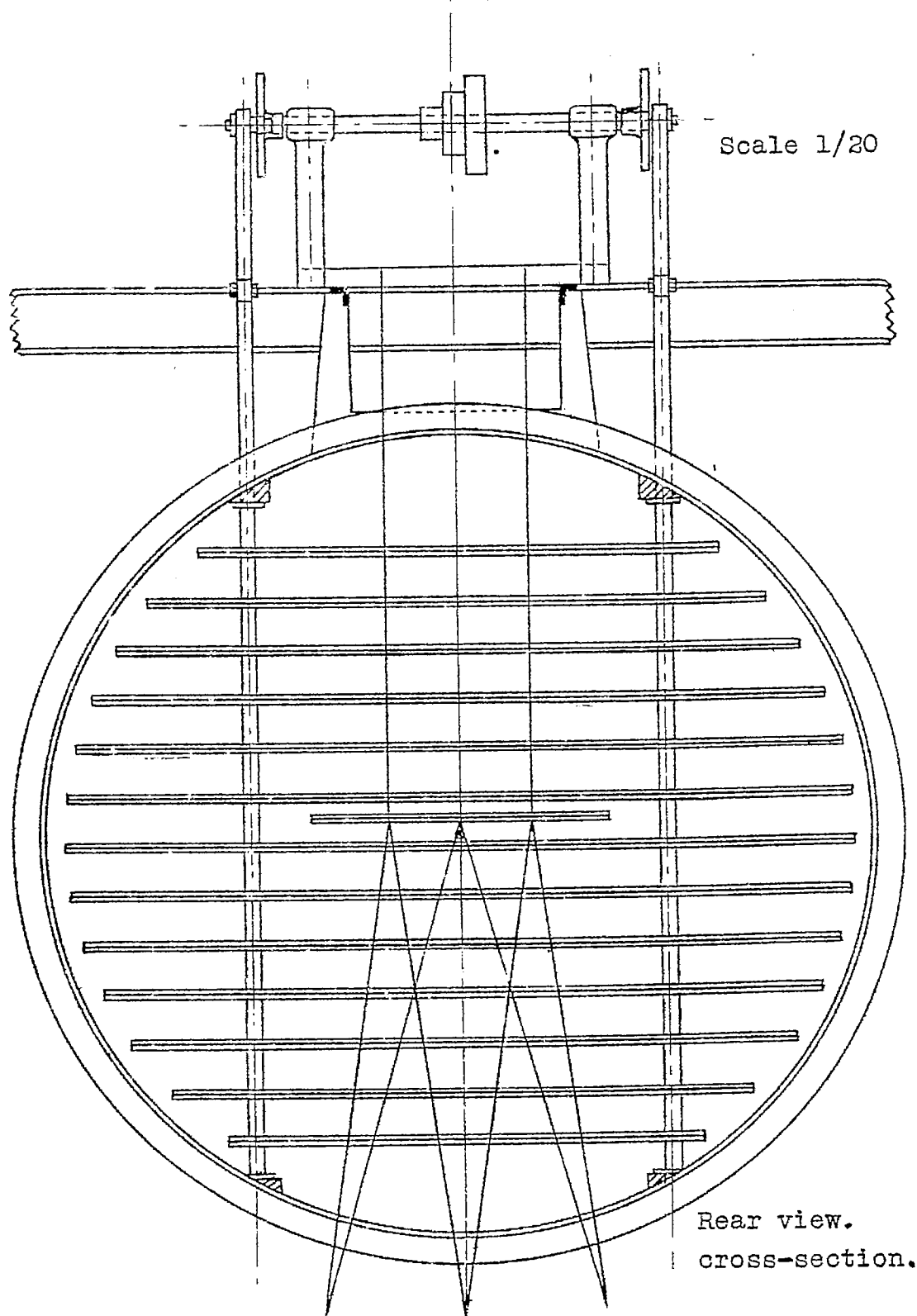
Fig. 1





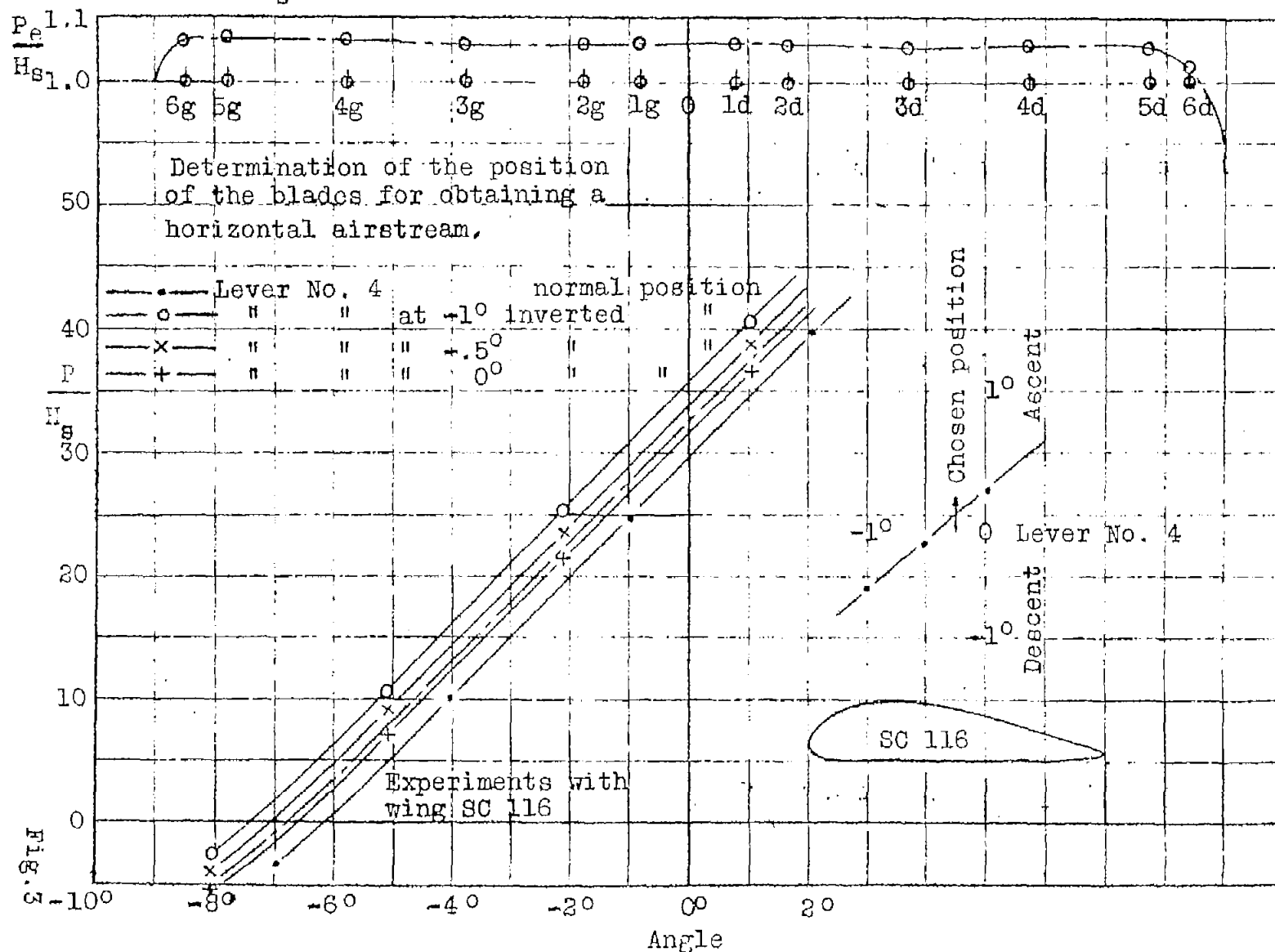
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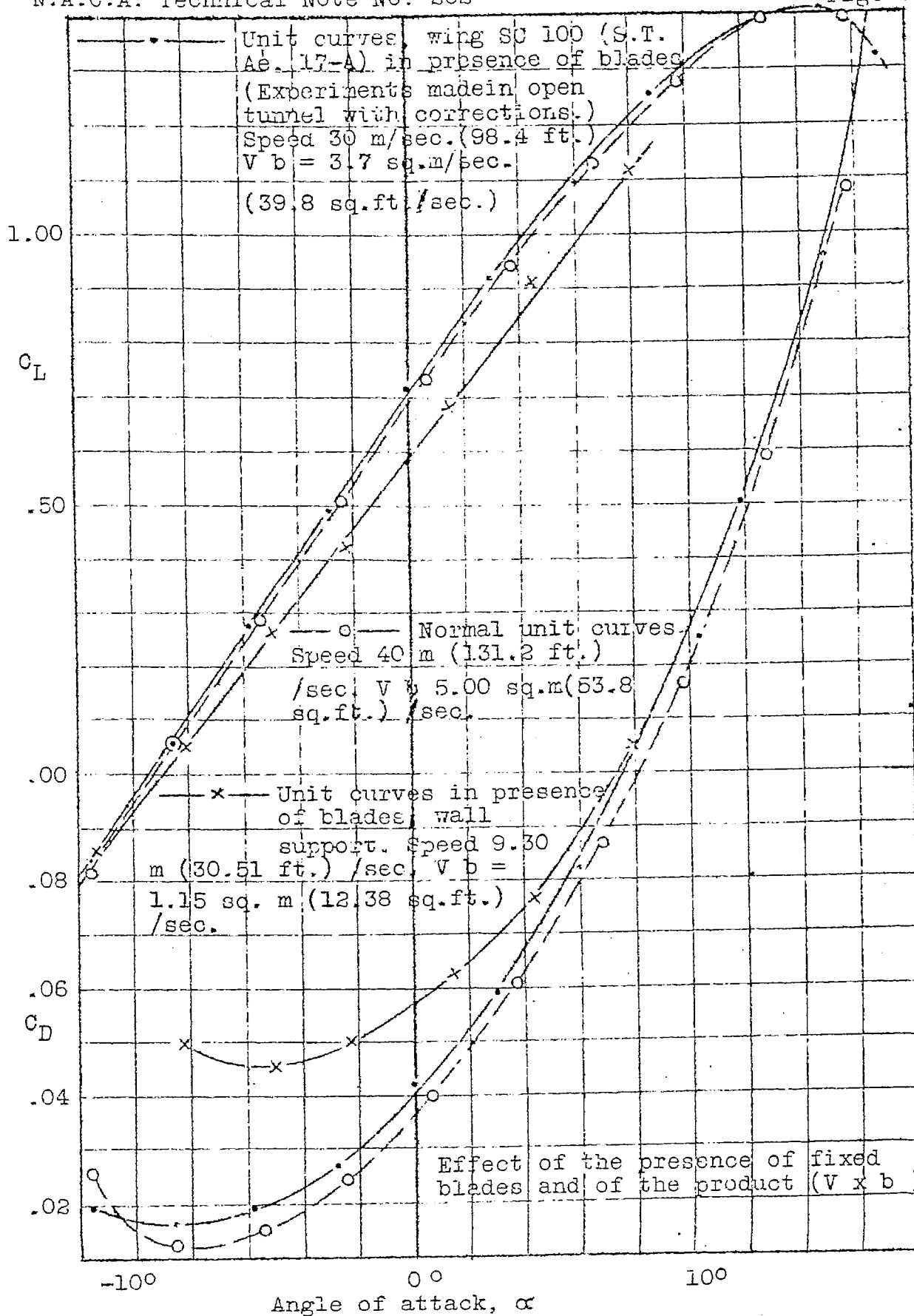




Distribution of speed along a horizontal diameter. (Blades at rest in mean horizontal position.)

Mean value  $\frac{P_e}{H_s} = 1.06$  whence  $V_m = \sqrt{16 \times 0.85 \times 1.06 H_s} = \sqrt{14.42 H_s}$  (with alcohol at 0.85)





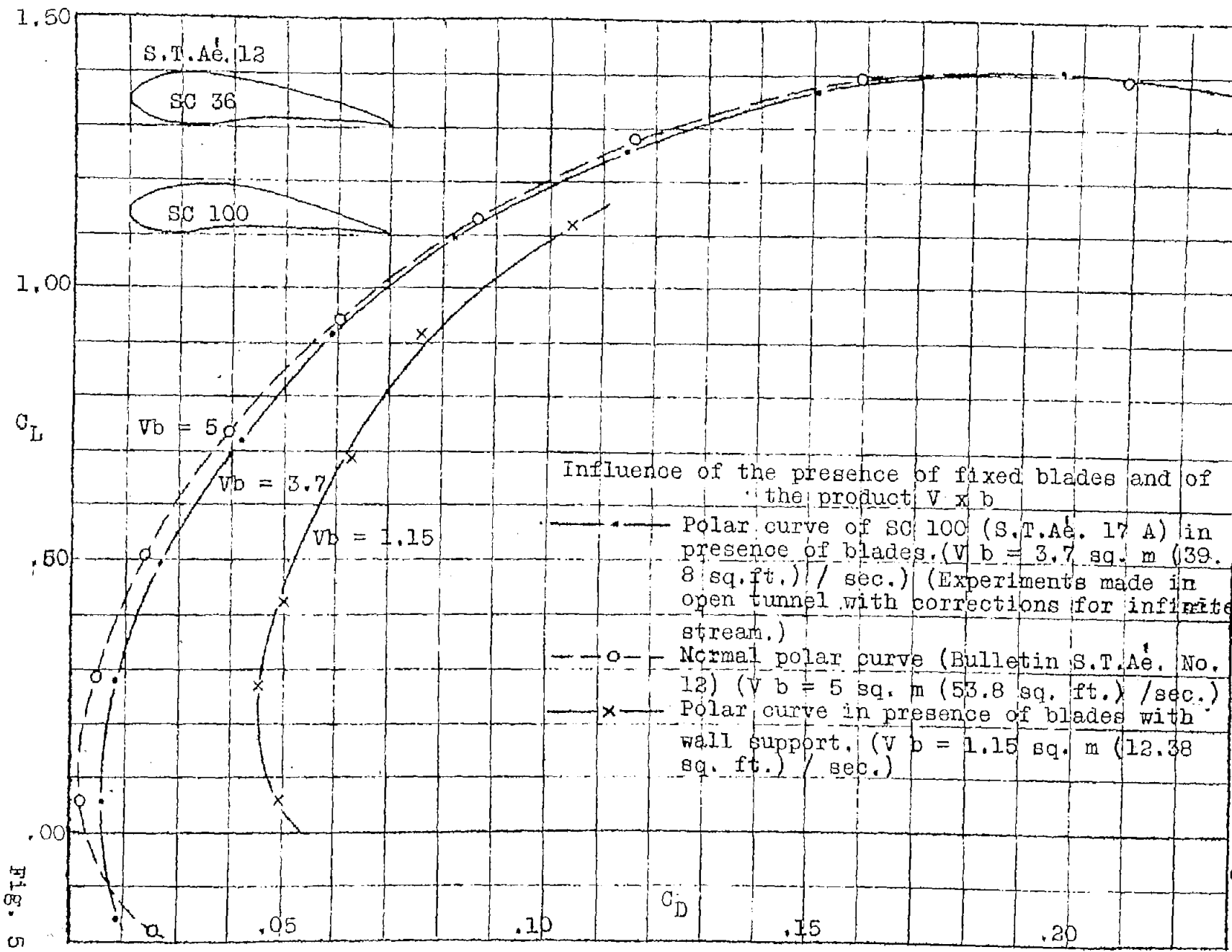
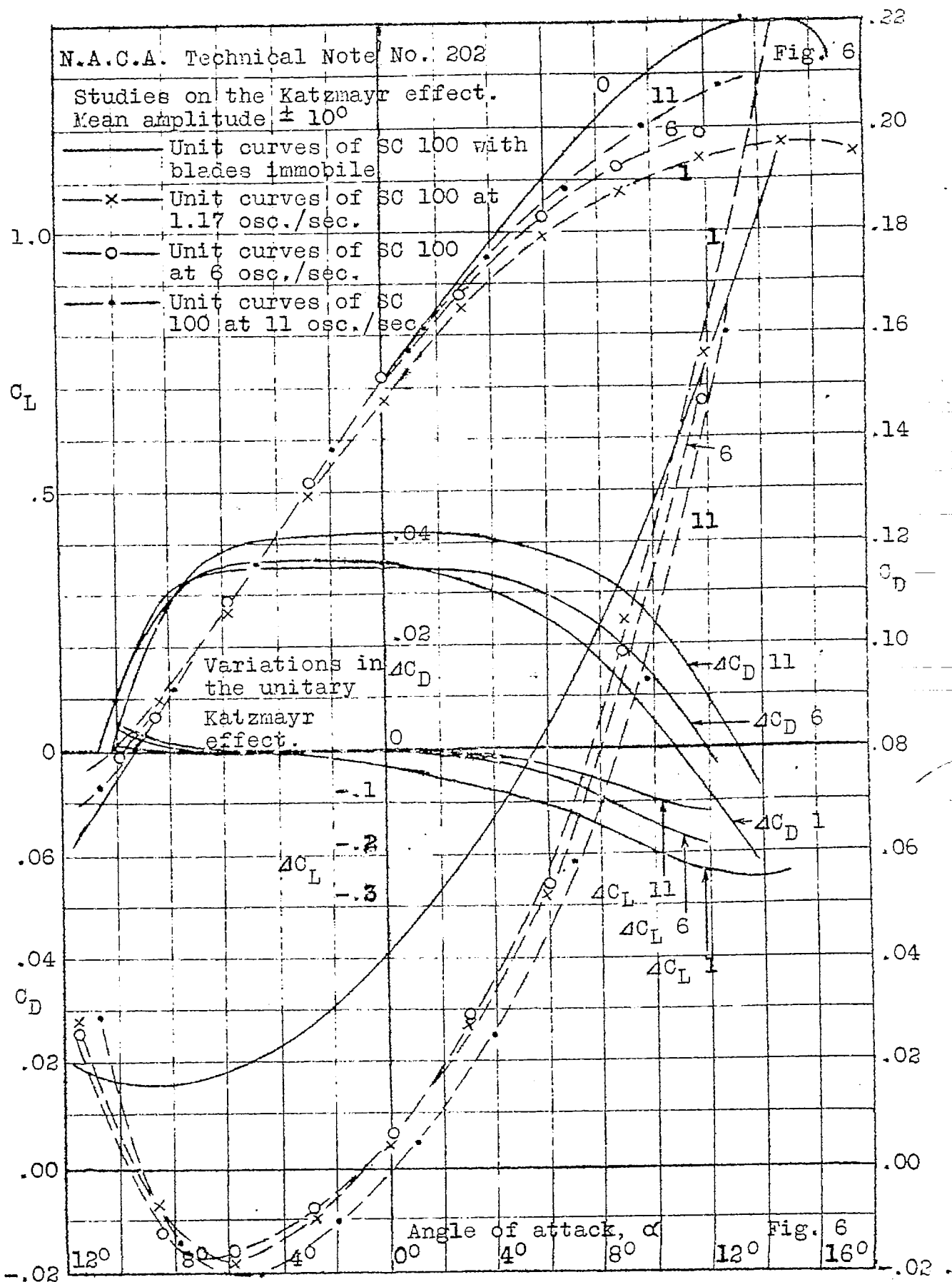
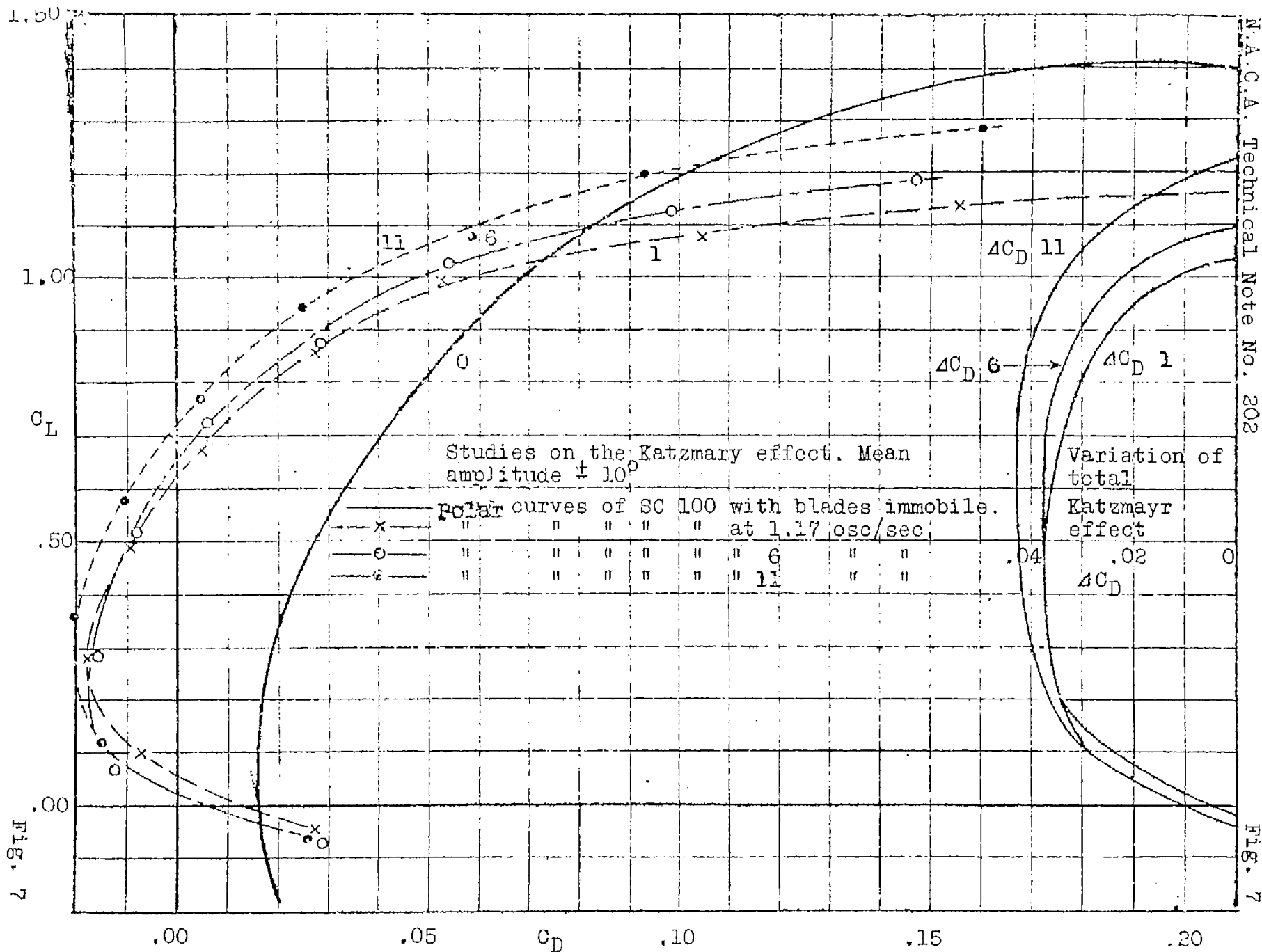


Fig. 5



Studies on the Katzmayer effect.  
Mean amplitude  $\pm 10^\circ$





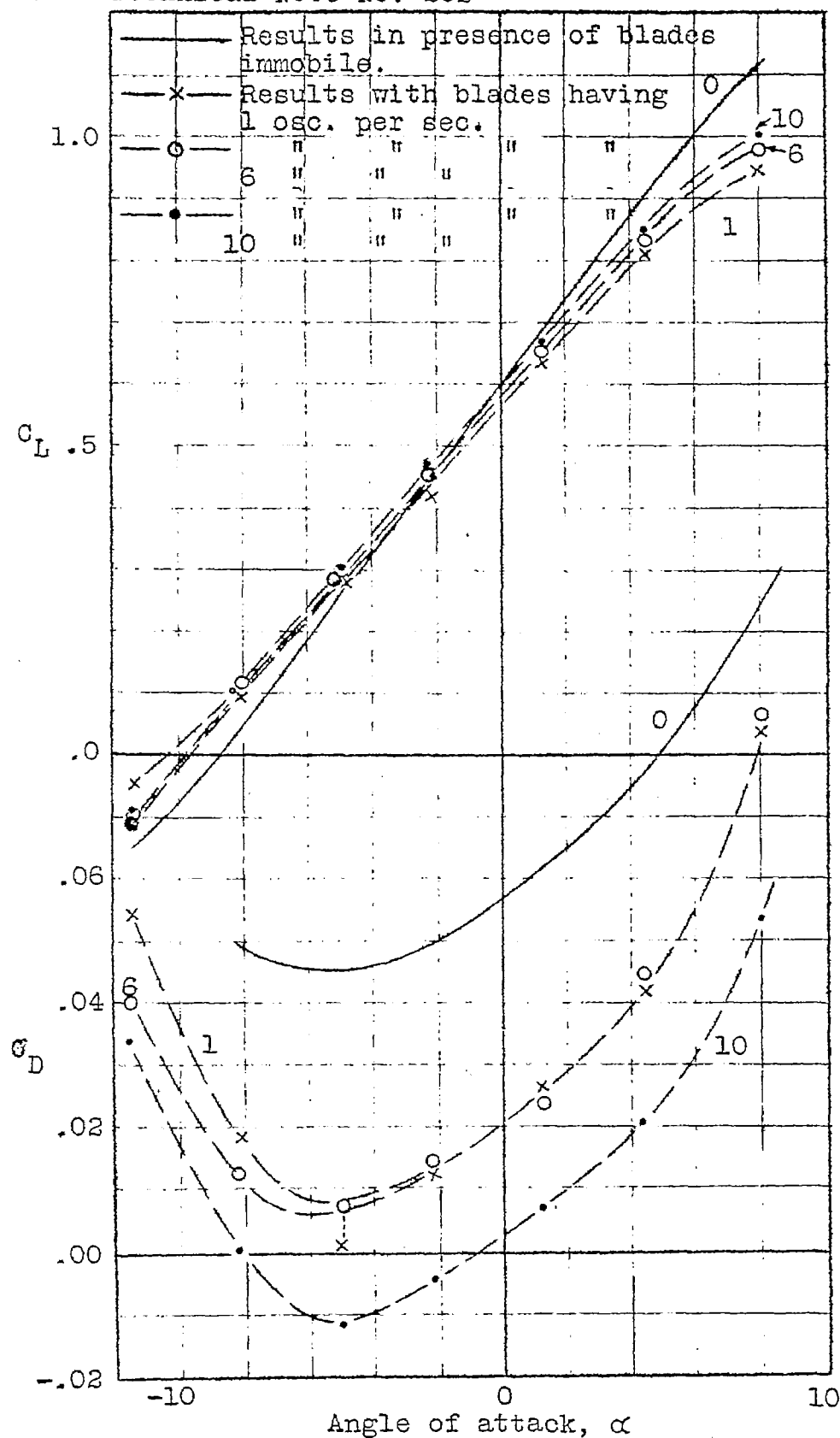


Fig. 8 Studies on the Katzmayr effect. Mean amplitude  $\pm 10^\circ$  to  $\pm 15^\circ$  Unit curves and polar curves of SC 100. Speed of air 9.30 m (30.51 ft.)

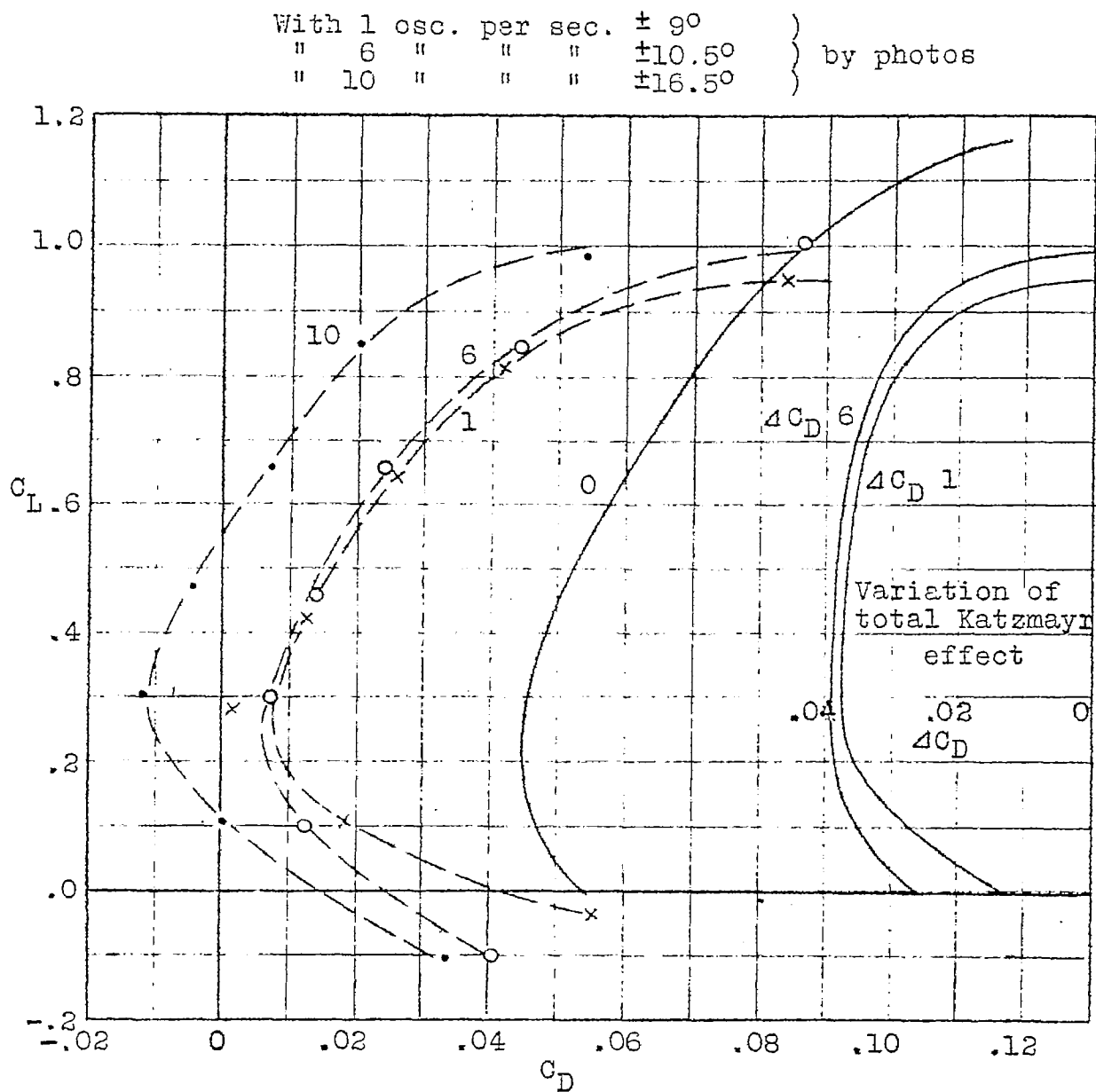


Fig. 9 True amplitudes measured with silk thread.  
 9.30 m (30.51 ft./sec.)

$V =$

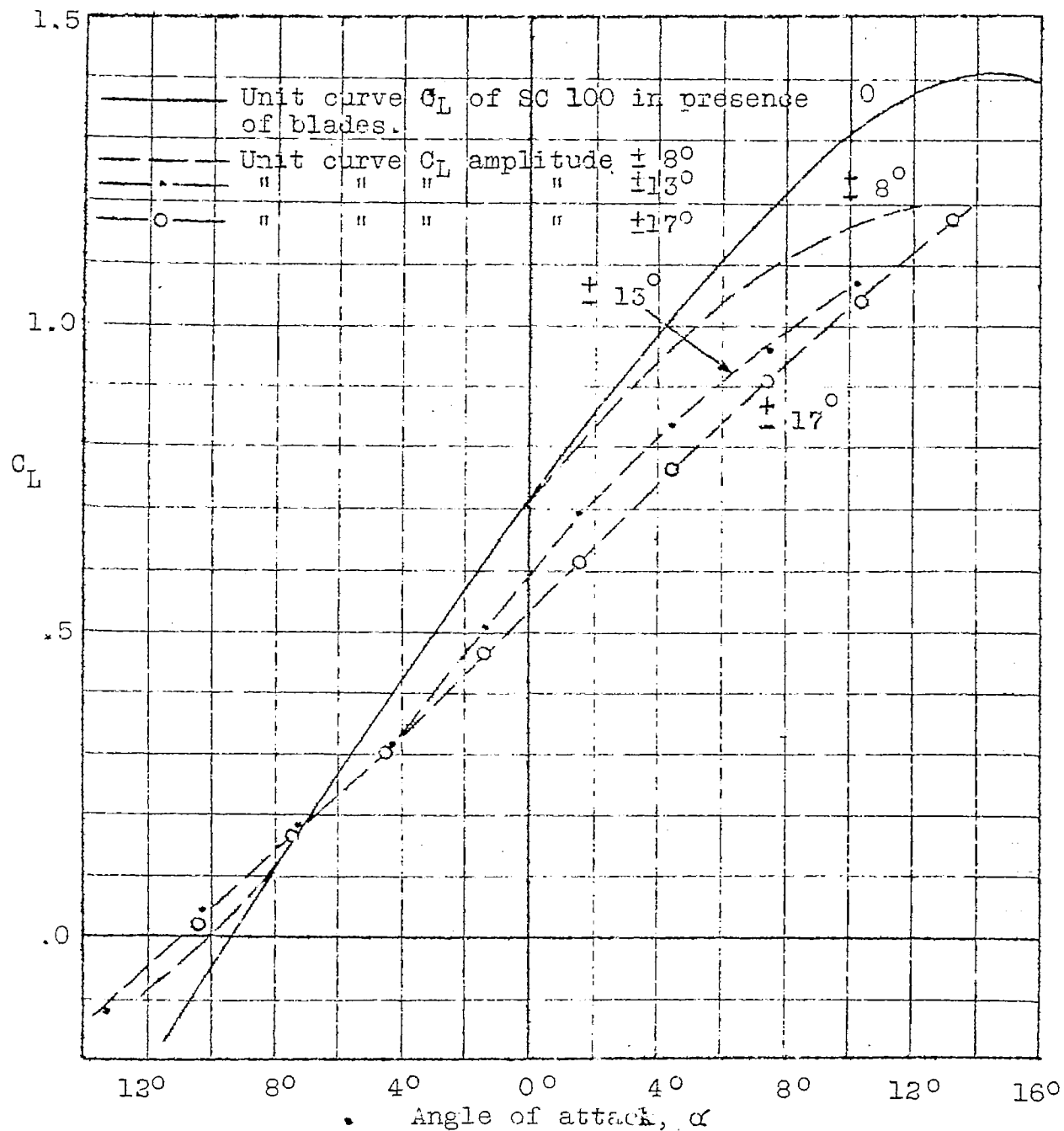
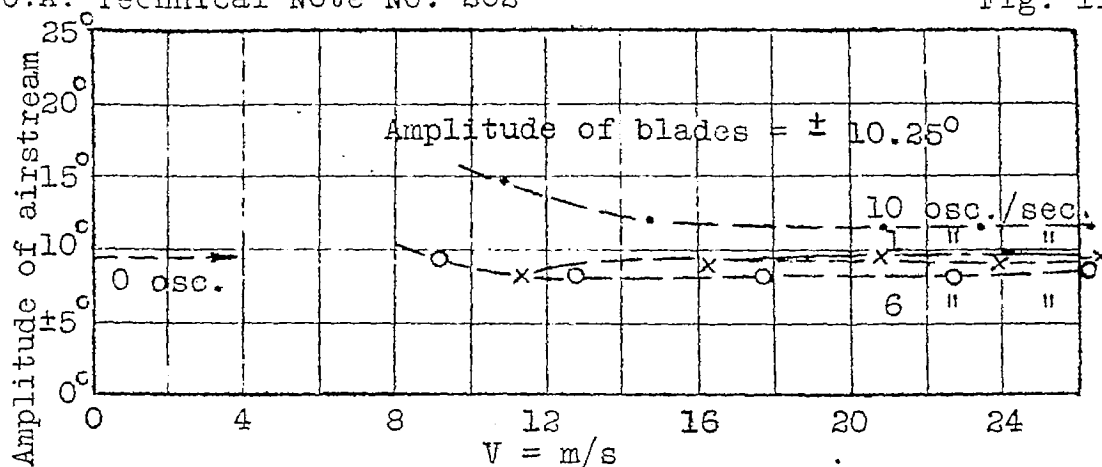
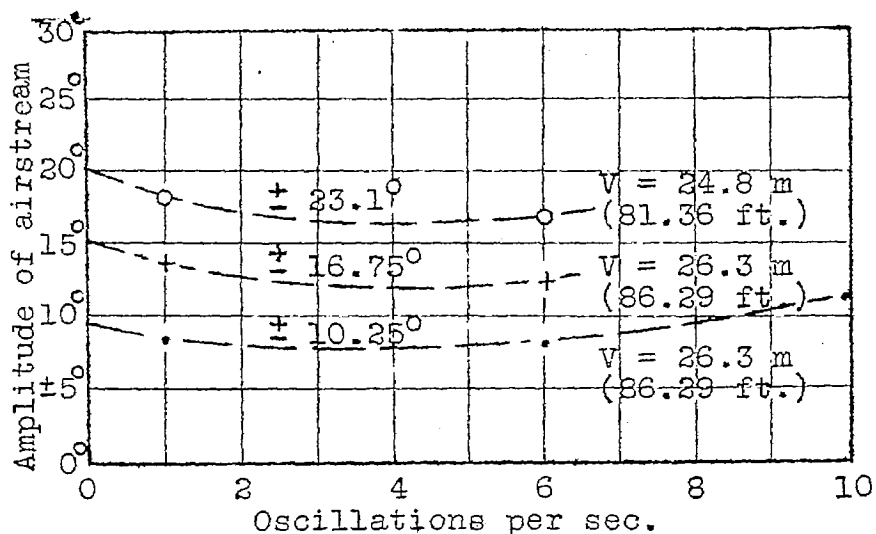
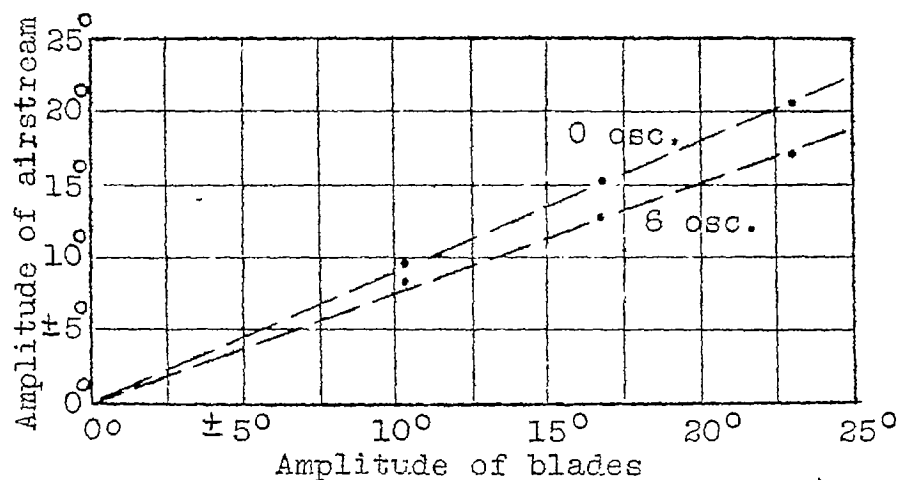


Fig. 10 Studies on the Katzmayr effect. Effect of amplitude of oscillation.



Variations in amplitude of oscillation of airstream with speed of airstream.



Variations of amplitude of oscillation of airstream with rate of oscillation.

Study on the Katzmayr effect.  
Effect of amplitude of oscillation.

— Unit curve  $C_D$  of SC 100 in presence of the blades  
 - - - Unit curve  $C_D$  amplitude  $\pm 8^\circ$   
 - - - " " " " "  $\pm 13^\circ$   
 - - - " " " " "  $\pm 17^\circ$   
 Rate : 6 osc./sec.

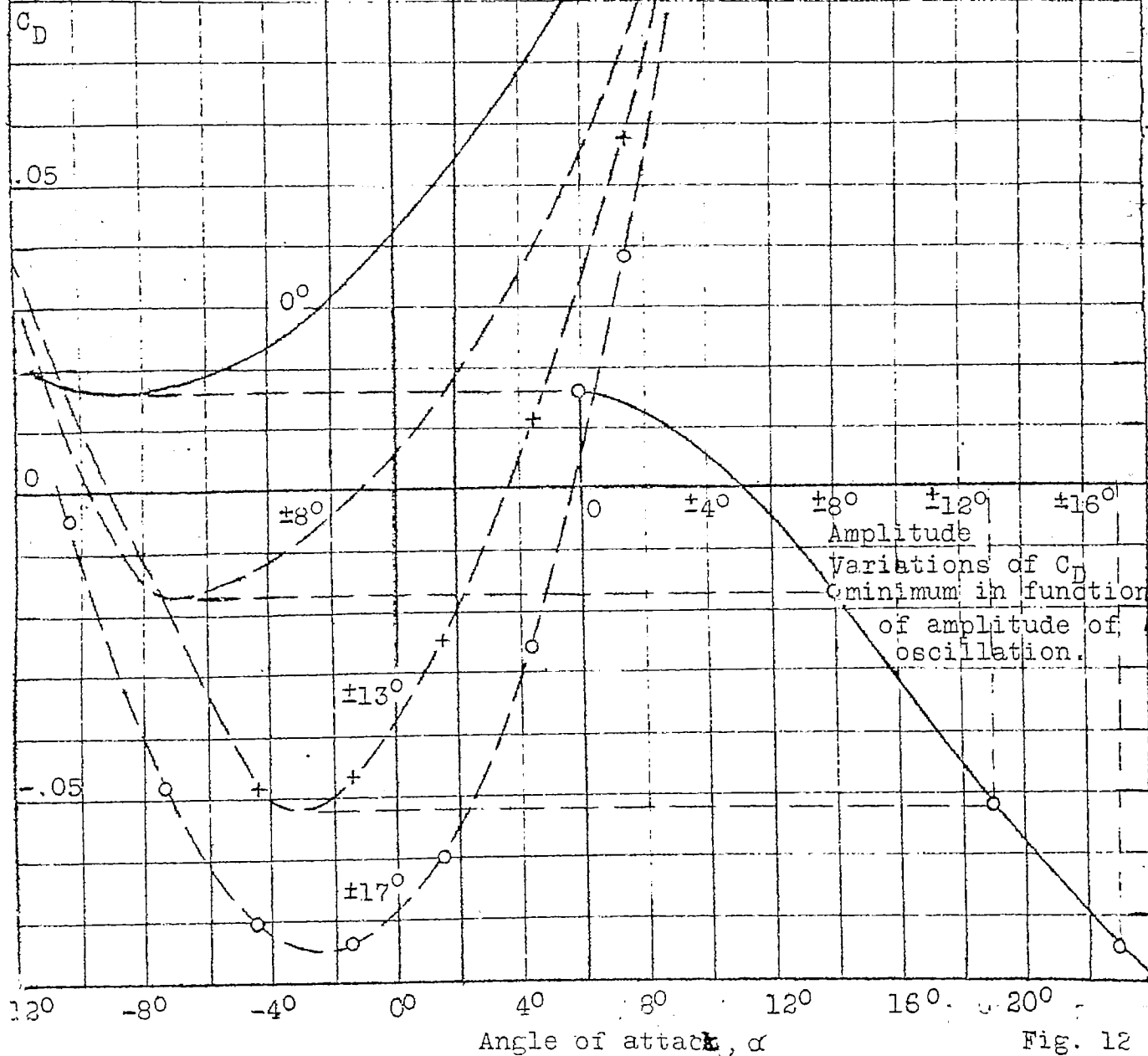


Fig. 12

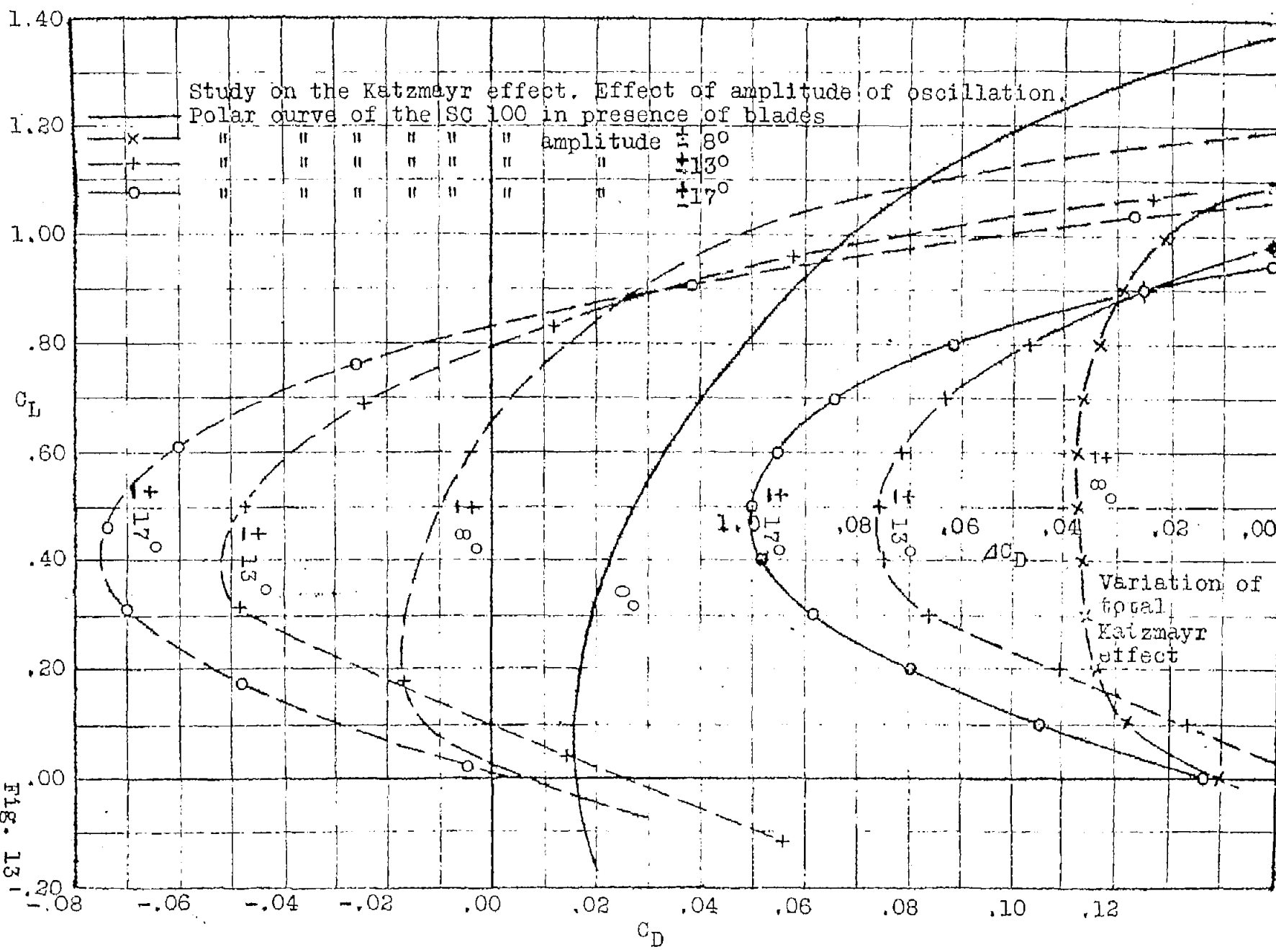


Fig. 13

Fig. 13



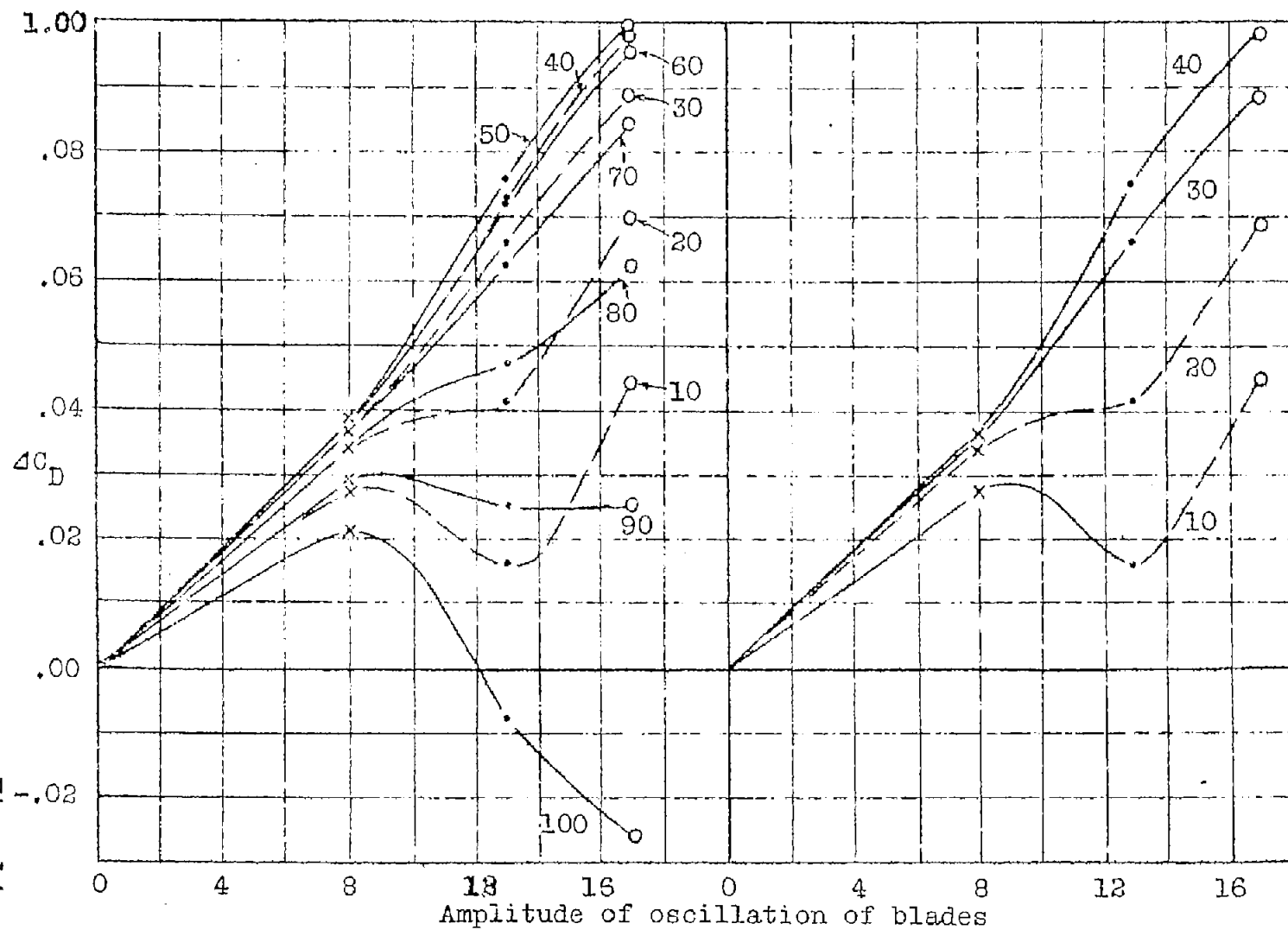
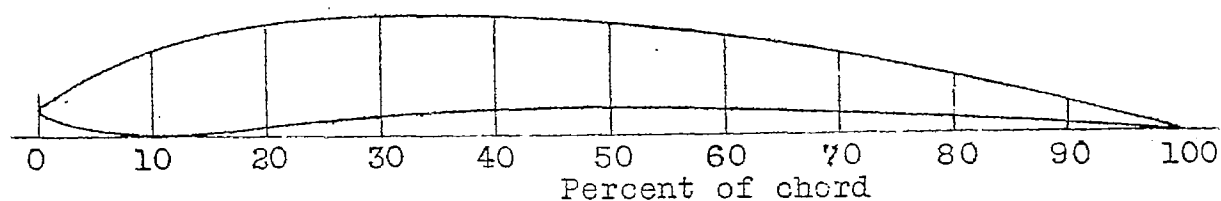
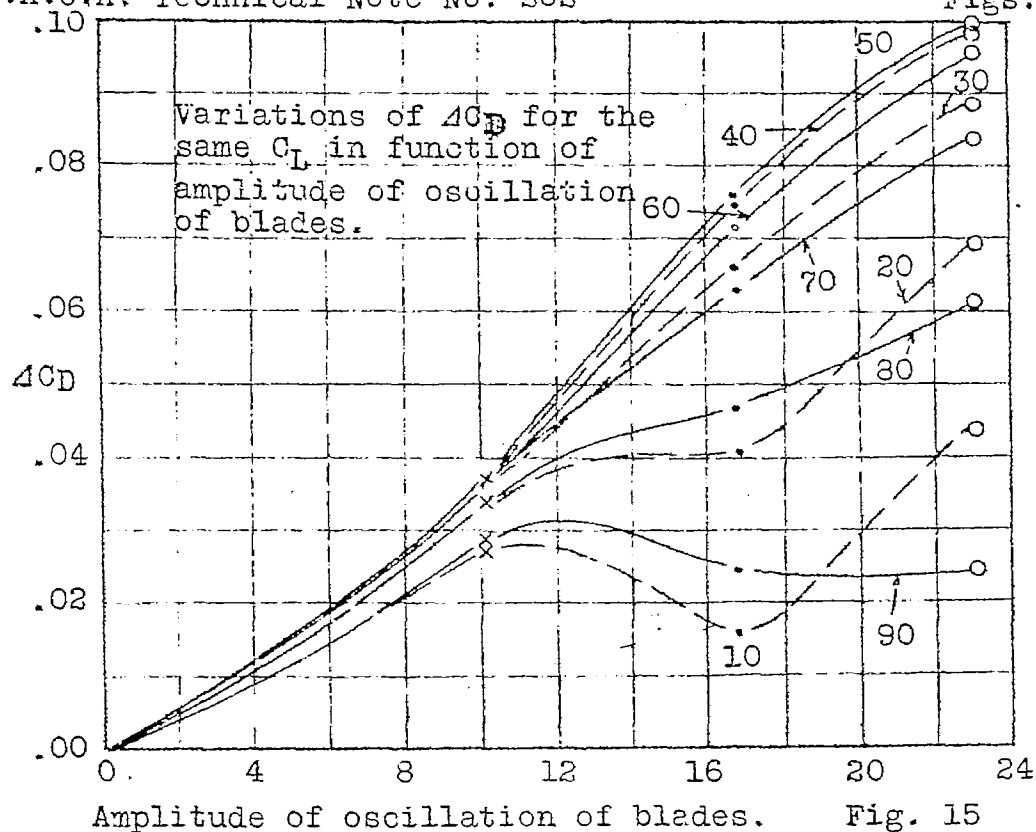


Fig. 14

Fig. 14

Variations of  $4C_D$  for the same  $C_L$  in function of amplitude of oscillation of airstream.



%	Upper	Lower	%	Upper	Lower	%	Upper	Lower
0	2.46	2.46	30	11.00	1.93	70	7.27	1.73
10	7.93	0.00	40	10.23	2.53	80	5.13	1.20
20	10.07	1.00	50	10.17	2.53	90	2.73	0.67
			60	9.13	2.27	100	0.00	0.00

Absolute coefficient for polar curves in study of Katzmayer effect are given in tables XVI to XXII

Fig. 16

Profile of airfoil SC-6

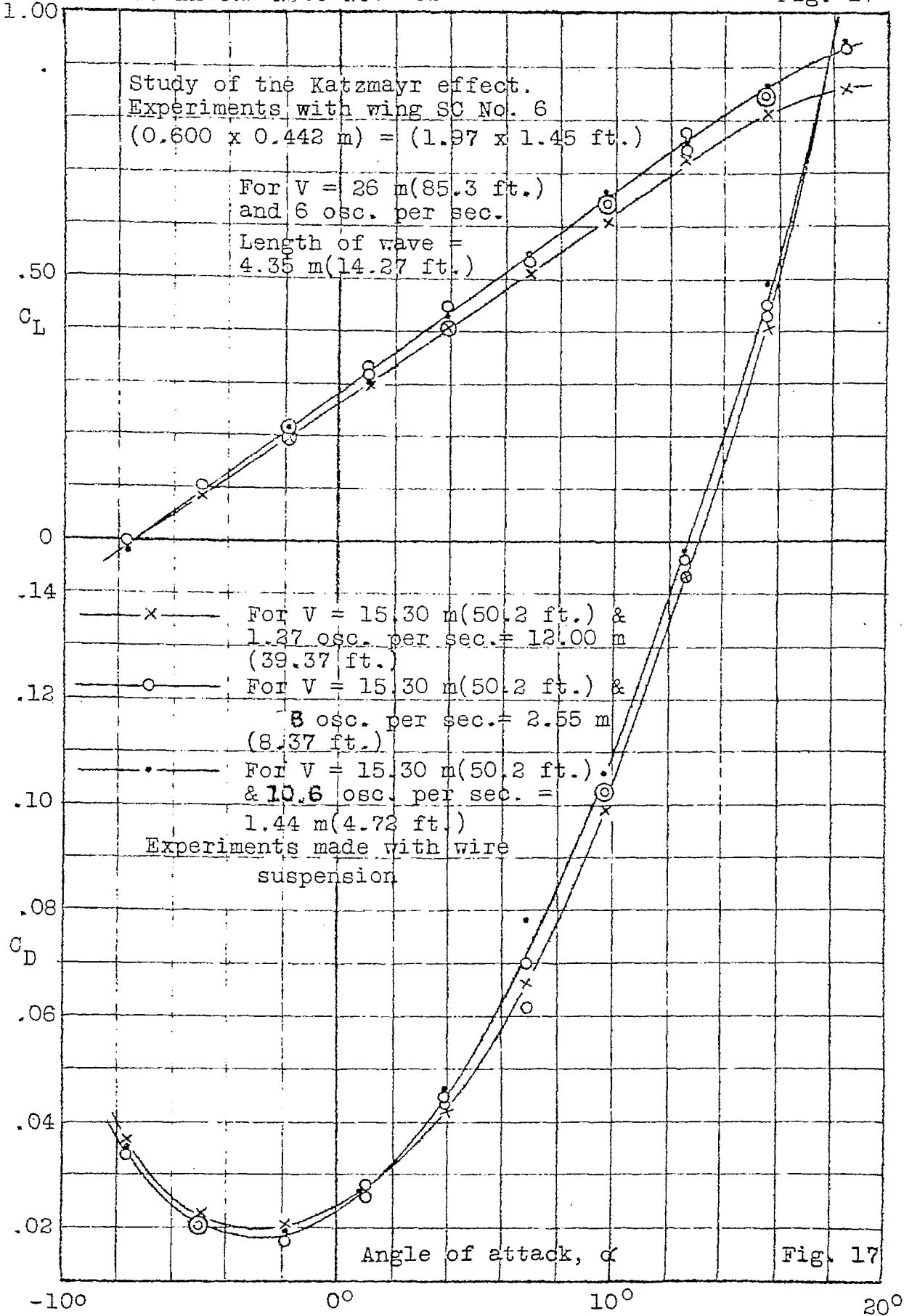
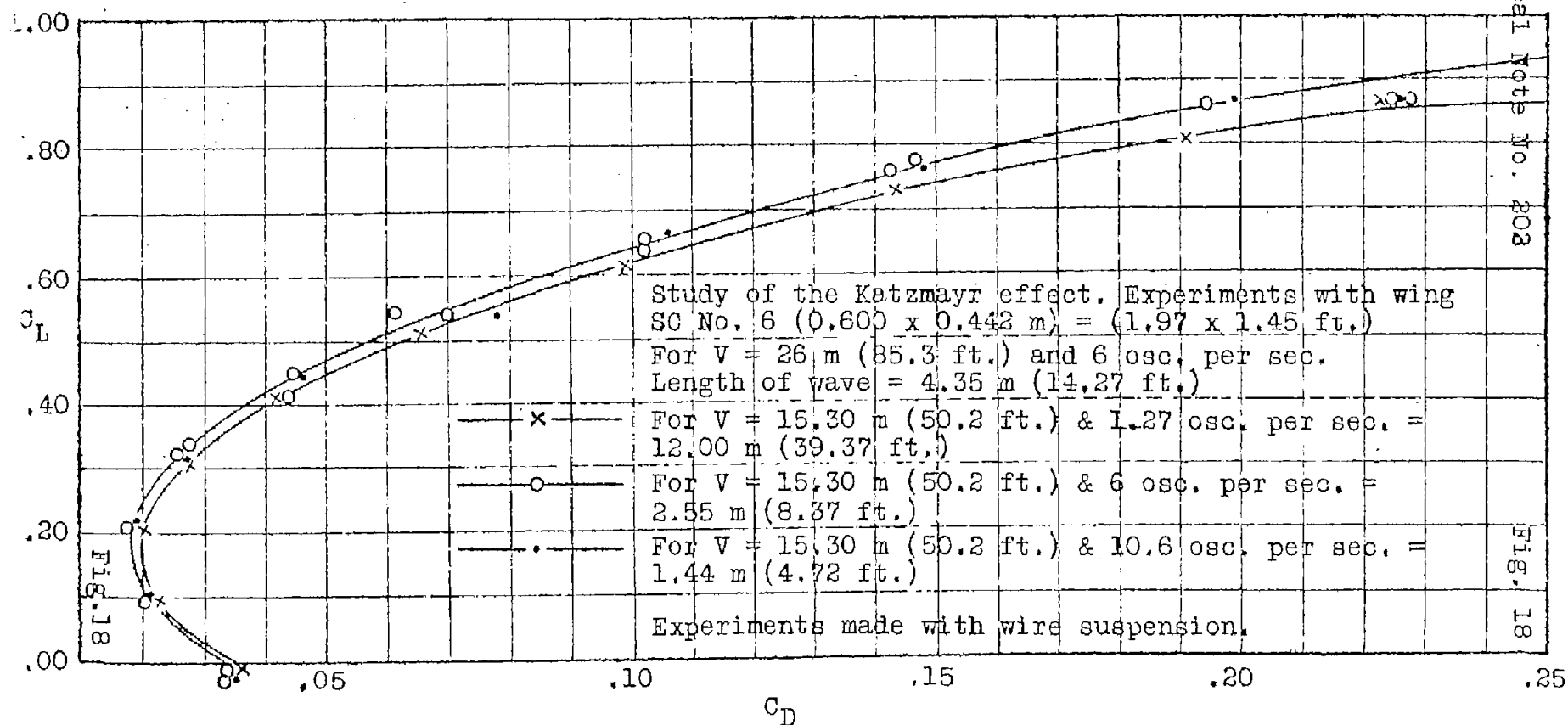
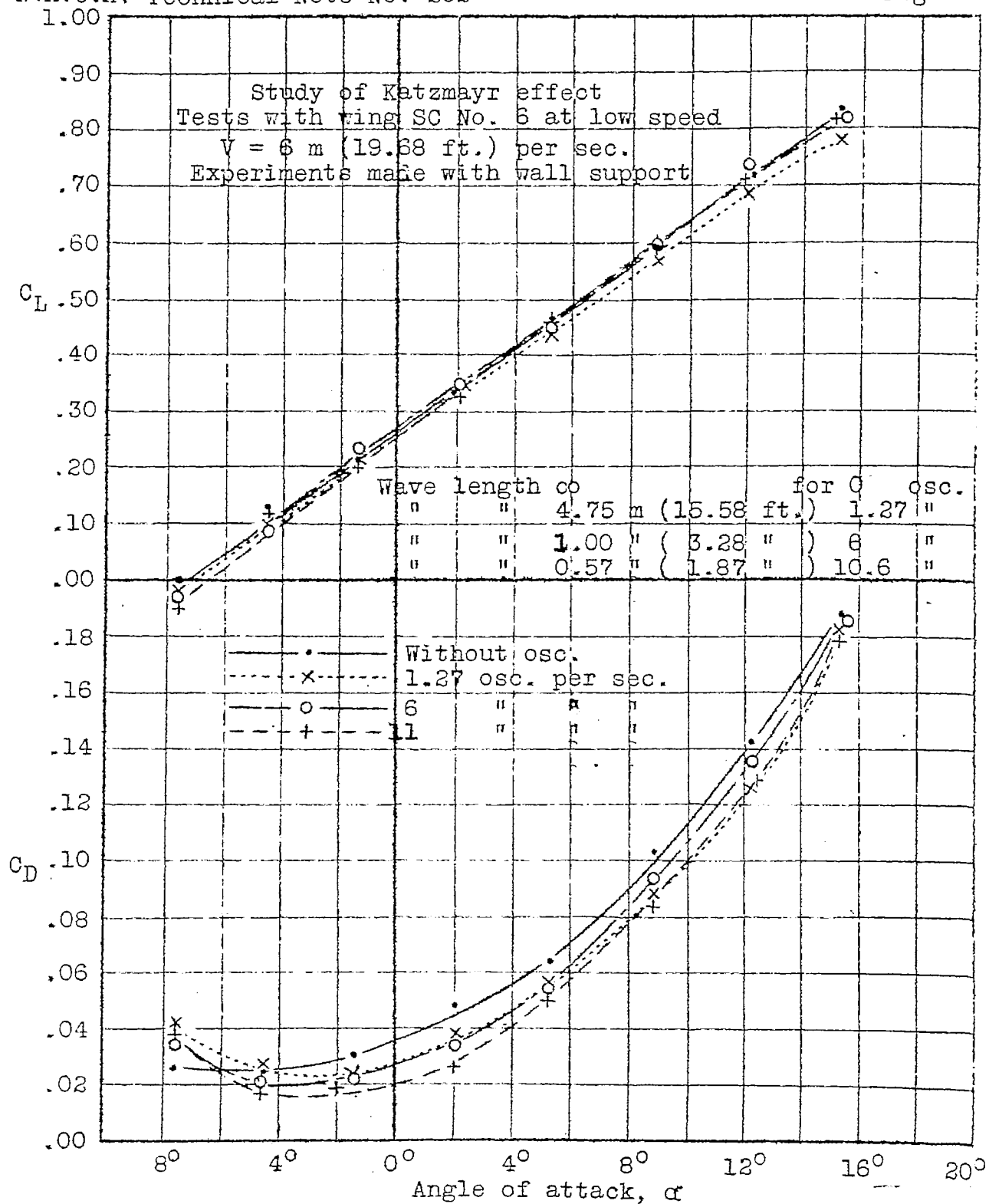


Fig. 17





Study of Katzmayr effect  
 Tests with wing SC No. 6 at low speed  
 $V = 6 \text{ m (19.68 ft.) per sec.}$   
 Experiments made with wall support

